"FLEXIBLES," WITH NOTES ON THE TESTING OF RUBBER.

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(*Paper read April* 18, 1907.)

SUMMARY OF CONTENTS.

1. *Introductory.*—Historical—Fire risks from flexibles—Mill wiring—Persistent arcs on flexibles—Fuses in ceiling roses. 2. *Conductors.*—Cable-makers Association standards—Cross-conductivity of stranded conductors—Extension of copper under small loads—Effect of temperature on tenacity of copper—Temperatures attained in lamp-holders—Effect of sulphur and tin on conductors—Effect of chemical fumes—"Gymp" flexible. 3. *Heating of Conductors due to Excessive Currents.*—Relative temperature rise with given currents in flexibles with various finishes—Kindling points of flexibles insulated with pure and vulcanised rubber. 4. *Insulation of Flexibles.*—Pure rubber strip from cut and spread sheet—Absorption of water by pure rubber—Vulcanised rubber—Vulcanisation coefficients—Tensile strength and elongation of vulcanised Para—Vulcanisation curves for Para. 5. *Oxidation of Rubber,* as an index of deterioration. 6. *Effect of High Temperature on Rubber.*—Loss of strength—Hardening—Stickiness—Behaviour of V.I.R. insulation on heating at 100° C. in air and carbon dioxide—Deterioration at 150° F. 7. *Hysteresis of Rubber.*—The mechanical hysteresis effect in cut and spread strip and vulcanised rubbers—Vulcanisation standards—Relative merits of the hysteresis method and the simple elongation test. 8. *The Stretching of Rubber.*—Effect of various admixtures on distensibility—Effect of dimensions of test pieces on breaking stress—Rate of stretching—Rate of recovery after stretching. 9. *Tests on Completed Flexibles.*—Tensile strength—Dielectric strength—Life tests by bending over a counterweight fitting and by bending through a right angle at a lamp-holder. 10. *Testing of Insulation.*—Significance of various tests—Chemical, electrical, and mechanical tests. 11. *Thickness of Insulation.*—Methods of applying vulcanised rubber insulation—Thicknesses employed for flexibles—Testing of longitudinal joints—Percentage of ash. 12. *Flexible Wiring Systems.*—The Peschel system—Hartmann and Braun's modifications—Costs. 13. *Attachments for Flexibles.*—Types of ceiling roses and lampholders in use in England and on the Continent—Loads under which stress is put on the terminals—Weight of fittings. 14. *The Attraction of Dust by Flexibles.*

BIBLIOGRAPHY.

APPENDICES.—*Regulations for flexibles.*—A. American; B. French; C. German. *Detail examination of flexibles.*—D. Vulcanised rubber now on the market—E. Old flexibles insulated with pure and vulcanised rubber.

I. INTRODUCTORY.

The employment of twin flexible conductors for pendant lamps has been evolved from the early usage of bringing down the circuit leads and connecting to the platinum loops sealed into the lamp bulbs. The flexible thus filled the double *rôle* of supplying energy to the lamps and at the same time served as their support. The wires were twisted together to render them more sightly, and the conductors were stranded to ensure the necessary flexibility for the lamps to hang vertically without adjustment and to overcome the inherent mechanical weakness of a solid copper wire of small diameter when subjected to repeated bending.

For the junction between the flexible and the circuit conductors, ceiling roses in the case of pendants, and plugs in the case of portable appliances have been evolved, while the junction between the flexible and the consuming device is now effected in the case of lamps by the lamp-holder, and in other cases by means of plugs, connectors, and sweating thimbles.

At the present time flexibles are extensively employed for the following purposes:—

Pendants and clusters.
Counterweight fittings.
Portable lamps.
Wiring of fittings (electrolier and fixture wire).
Connections to radiators and portable heating and cooking apparatus.
Connections to brushes of dynamos and motors.
Special systems of interior wiring.

These manifold uses and the varied conditions of environment in actual practice have been responsible for the number of grades in which flexible has been put upon the market. The type of insulation employed may be either a simple cotton covering with a protective braiding as used for dynamo flexible, one or more layers of pure rubber tape put on spirally under tension, or of vulcanised rubber or a combination of pure and vulcanised rubbers, together with a protective braiding.

There is a general consensus of opinion amongst engineers that the flexible is the weakest part of an electrical installation. If this is so, we are ourselves largely to blame for our neglect of the matter. It is curious to reflect that after the elaborate care that has been exercised to keep well-insulated conductors apart (when not enclosed in non-flammable tubes) in all other portions of the installation, we should have come to regard with complacency the violent forcing together of two comparatively poorly insulated conductors in positions where they are exposed to considerable heat and are liable to mechanical strains, as in the lamp-holder with single-hole cord-grip so commonly employed at the present time.

Unfortunately, there are no records published by the English fire offices in which fires caused by electricity are classified in detail. An examination of the reports of the Fire Salvage Association of Liverpool for the years 1894–1905 inclusive shows that during that period out of 9,711 fires in that city 666 were attributed to gas and only 74 to electricity, but as no details are given, it is impossible to say to what extent flexibles were concerned. Mr. W. W. Lackie* states that out of 35 fires during the years 1902–1904 attributed to electrical causes in the Glasgow system 5 were due to defective twin flexibles. The author has examined the admirable reports on fires due to electricity issued by the Electrical Bureau of the National Board of Fire Underwriters, New York, and has summarised the causes of such fires reported during the last year. Although the conditions obtaining in England and America are not precisely similar, yet the results given in Table I., below, may not be without interest as indicating the extent to which flexibles are concerned in such fires. These results do not include the total number of fires reported as attributable to electricity, but are taken from the summarised headings under which the causes of the fires have been classified. As a typical example of a detailed report of a fire of which flexible was the cause the following may be cited :—

"(3321) *Long pendant cord* had been knotted to take up surplus and to provide proper adjustment of lamp used for reading purposes over a bed. The constant abrasion and kinking of the insulation caused by this arrangement was finally sufficient to result in short circuit of flexible cord, which threw molten metal and burning insulation on the bed beneath."

TABLE I.

Summary of Reports of Electrical Fires. Electrical Bureau of the National Board of Fire Underwriters, New York, July, 1905, to July, 1906.

Cause.	No. of Fires.
Earths on motor and lighting circuits	71
Dynamos and motors	21
Rheostats	15
Blown fuses	12
Incandescent lamps	15
Crosses between high and low potential circuits ...	23
Lightning entering over service wires	13
†Overfused circuits...	3
†Lamp flexible hanging on nail	4
†Defective joints and contacts	13
†Short circuits on interior wiring...	79

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* *Journal Institution of Electrical Engineers*, vol. 35, 1905, p. 118

† Denotes items with which flexibles are concerned.

Faults in Flexible Installations.—On the Continent flexibles are employed more largely than in this country, in that their use is not restricted to lamps and portable appliances; but the wiring of the building itself is often carried out with flexibles supported on insulators. A description of the principal features of these flexible wiring systems is given later in this paper (see page 80), and the matter is only referred to here on account of the experience obtained on the Continent of flexibles in this wider field. In Appendices A, B, and C will be found *in extenso* the regulations, restrictions, specifications, and methods of testing in vogue in France, Germany, and the United States in connection with flexibles. These are given in detail, not only because it is usually instructive to compare the methods employed by different countries in dealing with a more or less common problem, but because a good deal of foreign flexible finds its way to the English market, and, further, because many of the art fittings imported from the Continent are provided with flexibles, which—although they might be satisfactory when used under the strictly specified conditions in the country of their origin—are here subjected to voltages and conditions for which they were never intended, with disastrous results.

With regard to the use of flexibles for wiring installations, which has an added interest to us at the present time in view of the desirability of cheapening the cost of wiring to small consumers, it has been found in Germany that unless the regulations laid down concerning this material (see Appendix C) are closely adhered to, and the best material employed, trouble is likely to ensue.

In the early days, when 110 volts only had to be dealt with, flexibles insulated with lapped rubber tape were successfully employed. When, however, 220 volts came into use this class of insulation was found to be insufficient, the faults mostly occurring in the switch wires. This was largely due to considerations of price which led to the employment of insulation material containing sometimes from 50 per cent. to 70 per cent. of rubber substitutes, and also to faulty manufacture in giving too small an overlap to the rubber tape spirals, so that in some cases the wire was uncovered. Under the new German regulations taped rubber flexibles may only be used in dry living rooms for pressures up to 125 volts. They may not be used under fabrics or for portable fittings, and may not be installed in cellars, under floors, in bedrooms, or halls. Vulcanised rubber in the form of a continuous sheath may, however, be used up to 1,000 volts for fixed apparatus and up to 500 volts for portable purposes. The trouble at 220 volts with taped rubber flexibles is due, not so much to a direct short circuit, which would blow the fuses, as to persistent arcs of low current value, which are carried by the fuses.

As already stated, these faults have been found to occur most frequently in the switch wires, and a reference to Fig. 1 will show the reason for this. It is evident that a short occurring at A or B would, by short-circuiting the lamp or other consuming device, allow of a considerable current rush, and blow the fuses; whereas if a short occurred in the switch wire at C only the switch is short-circuited, and the current in the arc is limited to that of the lamp or consuming device in the circuit. The arc thus formed travels slowly up the wires until the lamp leads are involved, when the fuses will blow. To obviate this trouble with the switch wires Coninx* proposes to have laid up with the flexible for the switch connection a third wire, which should, if the switch is in the positive wire, be connected to the negative main at one end, and be carried down to the switch and there sealed off without being connected to it. A short-circuit in the switch wires would involve this third wire, and thus ensure the fuses blowing. The arrangement is shown diagrammatically in Fig. 2.

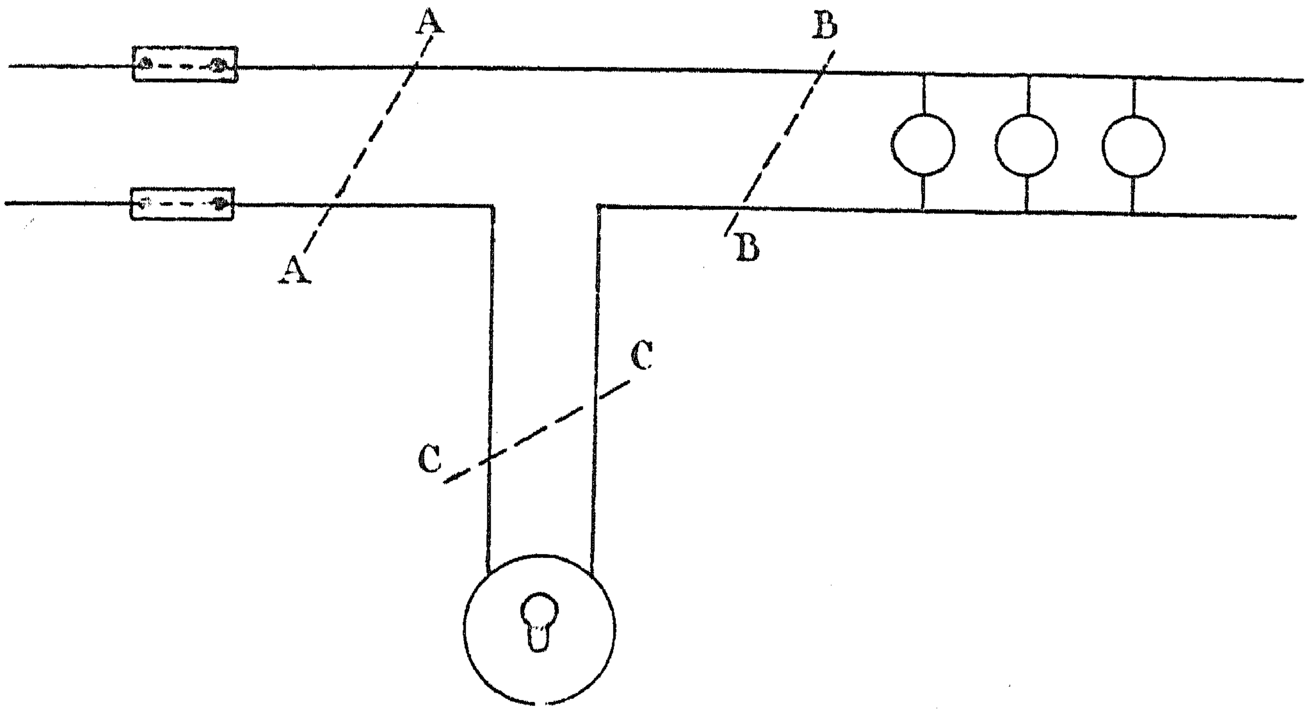

FIG. 1.

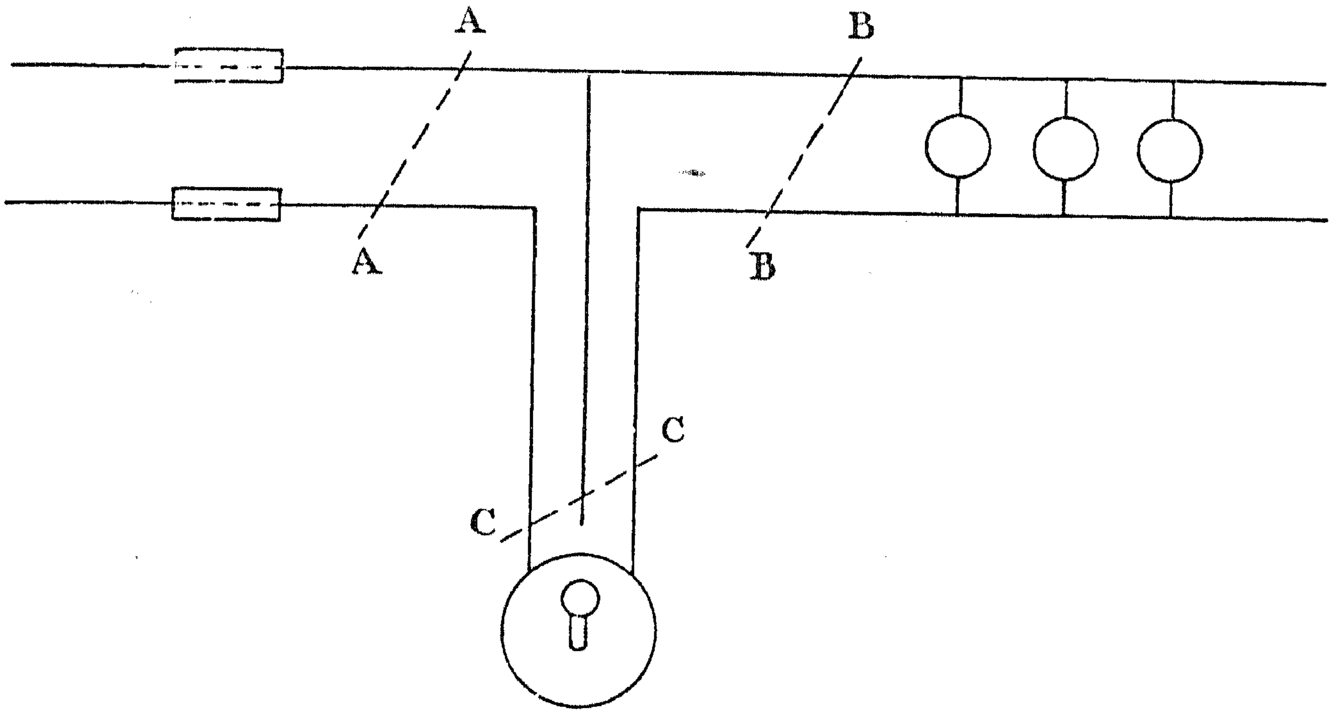

FIG. 2.

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* *Handbuch der Electrotechnik*, vol. 6, part 2, p. 394.

It is not unusual in Lancashire cotton mills, where the air is highly charged with moisture, and the flexibles are regularly brushed down in order to rid them of the adherent fluff with the brush used for cleaning down the machines, which is in consequence oily, to find that persistent arcs of low current value, and too small to blow the circuit fuses, are formed in the flexibles for pendant lamps. The arc travels up the flexible in the manner already referred to, but the limitation of the current in this case is due to the formation of a high-resistance arc across the carbonised insulation. It is interesting to note in this connection that in the United States and Germany the regulations call for an outer covering for the flexible, which shall be non-flammable. In spite of the fact that this regulation has been in force for many years the author is unaware that it is being actually complied with in a satisfactory manner. In mill and factory lighting, moreover, it is impossible for economic reasons to employ only 5-ampere circuits where long aisles are to be lit, consequently the blowing of a fuse brought about by the failure of a flexible may extinguish a large number of lights and result in the sudden throwing off of a large load and considerable confusion with the work. A return to the practice of fusing ceiling roses would therefore seem to be desirable in such cases, as the small fuse in the holder would in the first place be more likely to blow on the formation of the arc, and, secondly, would finally isolate the faulty flexible without interfering with the remainder of the circuit. Fuses in ceiling roses were abandoned chiefly because their inaccessible position rendered them likely to be largely over-fused for the sake of avoiding the trouble of replacement. This objection was valid when the branch circuits carried a large number of lamps, as, in the case of a ceiling rose fuse not blowing for a fault in the flexible, a considerable current might be fed through it to the fault. By limiting the branch circuit fuses to a carrying capacity of 5 amperes this danger is minimised, and the ceiling rose fuse, if fairly rated then, only becomes a source of annoyance, and we are well rid of it. But in the case of the lighting of long aisles the general safety of the circuit would undoubtedly be improved, and the amount of annoyance occasioned by the blowing of a fuse would certainly be curtailed by the re-introduction of the fused ceiling rose.

II. CONDUCTORS.

The conductors for flexibles are usually all twisted in one direction; they are sometimes, however, not twisted at all. This latter form is not desirable for any conductor that has to work backwards and forwards over a pulley, as the stress is not distributed evenly over the wires, which in consequence are liable to break.

It is very desirable that the number and gauge of wires for flexibles should be standardised, as cable makers are called upon at the present time to make up all sorts of odd sections.

The following particulars of conductors have recently been agreed by the Cable Makers' Association as being standard for flexibles. Table II. shows the number of wires of a given gauge with the equivalent solid wire. Table III. shows the number of wires of given gauge with the equivalent total sectional area in square inches. The vulcanised rubber C.M.A. flexible, which is the only standard material now on the market, consists of tinned copper wire 0·0076 in. diameter (No. 36 S.W.G.), made up as follows :—

Size.	Equivalent in Solid Wire.	Thickness of Insulation in Mils.
23/36	20	34
40/36	18	35
70/36	16	36
90/36	15	37
110/36	14	38

TABLE II.

CABLE MAKERS' ASSOCIATION STANDARD FLEXIBLES.

Number of Wires in Flexibles with Equivalent Solid Wire S.W.G.

Equivalent Solid Wire S.W.G.	No. 40.	No. 38.	No. 36.	No. 33.	No. 30.	No. 28.	No. 26.
23	25	16	10	—	—	—	—
22	34	22	14	—	—	—	—
21	44	29	18	10	—	—	—
20	56	36	22	13	—	—	—
19	70	45	28	16	10	—	—
18	100	64	40	23	15	11	—
17	136	87	54	31	21	14	10
16	178	114	71	41	27	19	13
15	225	144	90	52	34	24	16
14	278	178	111	64	42	29	20
13	367	235	147	84	55	39	26
12	469	301	187	108	70	49	33

TABLE III.

CABLE MAKERS' ASSOCIATION STANDARD FLEXIBLES.

Number of Wires in Flexibles with Equivalent Cross-sectional Area.

Equivalent Sq. In.	No. 40 S.W.G.	No. 38 S.W.G.	No. 36 S.W.G.	No. 33 S.W.G.	No. 30 S.W.G.	No. 28 S.W.G.	No. 26 S.W.G.
0·010	552	354	220	127	83	58	39
0·015	828	531	330	191	125	87	59
0·020	1,105	708	441	254	166	116	79
0·025	1,380	885	551	318	208	145	98
0·030	1,656	1,062	661	382	249	174	118
0·040	—	1,416	882	509	331	233	157
0·050	—	1,770	1,102	637	414	291	196
0·075	—	—	1,655	955	623	436	295
0·100	—	—	—	1,273	830	581	393
0·150	—	—	—	1,910	1,240	872	589
0·200	—	—	—	—	1,656	1,163	786
0·250	—	—	—	—	—	1,454	982
0·300	—	—	—	—	—	1,744	1,179
0·350	—	—	—	—	—	—	1,375
0·400	—	—	—	—	—	—	1,572
0·450	—	—	—	—	—	—	1,768
0·500	—	—	—	—	—	—	1,964

Conductivity of Small Stranded Conductors.—The following tests were made to determine whether the conductivity of a twisted stranded conductor is the same as that of a solid conductor of equivalent cross-sectional area. The experiments were made with both pure and tinned copper wires as supplied by the cable makers. The diameters of the tinned wires were found to be slightly greater

TABLE IV.

Diameters of Tinned Copper Wires for Flexibles.

Firm.	Nominal Size S.W.G.	Standard S.W.G. Diameter in Inches.	Diameter of Tinned Wires in Inches.
A	36	0·0076	0·0080
B	36	0·0076	0·0078
D	36	0·0076	0·0085
D	38	0·0060	0·0066

than their nominal gauges, the wires being drawn to standard gauge and then tinned. The thickness of the tinned coating varied with different samples, as shown in Table IV.

The conductivity of the stranded conductors as determined with the Kelvin double bridge is given in Table V.; as a check on the results the resistance of a single solid conductor No. 18 S.W.G. was measured and compared with the resistance per yard of equivalent solid conductors as given by tables. These results are placed at the bottom of Table V. The resistance tables referred to are in general use and agree with the Engineering Standards Committee's standards for copper conductors.

TABLE V.

Conductivity of Stranded Conductors.

Firm.	Nominal Size in S.W.G.	Copper Conductor.	Measured Res. per Yard of Stranded Conductor.	Res. per Yard Equiv. Solid (from Tables).	Measured Conductivity of Stranded. / Conductivity of Nominal Equivalent Solid.
B	23/36	Tinned	0·02305	0·02305	1·000
B	40/36	,,	0·01328	0·01328	1·000
B	35/40	Pure	0·03535	0·03799	1·075
B	70/40	,,	0·01780	0·01913	1·075
B	35/38	,,	0·02300	0·02429	1·055
B	61/38	,,	0·01320	0·01393	1·055
A	23/36	Tinned	0·02284	0·02305	1·010
A	40/36	,,	0·01300	0·01328	1·016
A	56/40	Pure	0·02135	0·02362	1·108
A	100/40	,,	0·01222	0·01328	1·085
D	27/38	Tinned	0·02877	0·03150	1·095
D	23/36	,,	0·02130	0·02305	1·082
	1/18	,,	0·01330	0·01328	Ratio of Measured to Tabled Conductivity. 0·9985

A consideration of Table V. shows that the conductivity of stranded flexibles may be taken as at least equivalent to the standard values for their equivalent solid sections. The comparatively large excess of conductivity shown by some samples is due to the constituent wires being actually larger than their nominal standard gauge. The question of cross conductivity may also affect this result.

Assuming that the current flows not only along the twisted strands of the conductors, but also straight from strand to strand through the lines of contact, the effective conducting cross-sectional area will be greater than that of the equivalent solid section of its constituent conductors, and its resistance will therefore be lower. This principle is illustrated in Fig. 3, which represents a rectangular copper bar closely overwound with a second bar of similar section, the conducting area being manifestly much greater than the combined cross-sectional areas of the two bars.

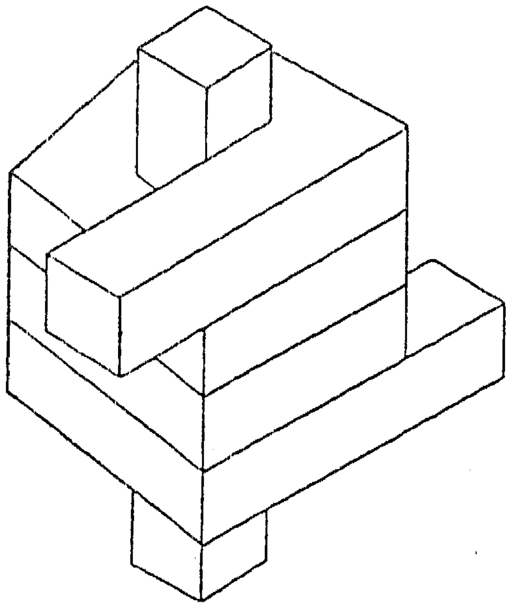

FIG. 3.

With a lay of 1 in 20, however, it can be shown by calculation that the increase in cross-sectional area is of the order of 0·2 per cent., and against this effect has to be set the increase in resistance due to the increase in length of the conductor. The matter is a difficult one to deal with in the case of flexibles, as the resistance of wires of small diameter is perceptibly increased by bending or winding, and further the errors in measuring the diameter affect the computed areas far more seriously than is the case with larger wires.

This matter is of interest in connection with the tolerance for tinning and lay of conductors, and Mr. A. E. Moore, who kindly carried out these experiments for the author, proposes to extend them to cables of larger sizes, both tinned and untinned. In general the conductors for service with vulcanised rubber are tinned, whereas those for use with taped rubber are not.

There are four causes of weakness in the conductors which would appear to operate in actual practice:—

(1) Extension of the wires by bending when under small loads.
(2) Loss of tenacity due to increase of temperature at the lampholder.
(3) Corrosion of the wires due to sulphur from the vulcanising compound.
(4) Corrosion of the wires due to chemical fumes in the air.

(1) *Extension of the Wires by bending when under small Loads.*—Ercolini * has recently investigated in considerable detail the extension of copper wire when wound and unwound under tension upon cylinders of various diameters. He experimented with copper wire 0·04 cm. (16 mils.) diameter wound upon iron cylinders 1, 2, and 4 cm. diameter respectively under tensions varying from 250 to 3,000 grammes (0·5 to 6·6 lbs.). He found that with successive winding and unwinding the wire stretched as much as 84 per cent. before breaking, and that under a tension which produces an insignificant stretching if applied in the ordinary way.

It would seem probable that this cause would operate in the case of flexibles which are repeatedly bent at the lamp-holder or round any surface of small radius. The author has carefully examined the fractured ends of the conductors used in the bending tests described on page 72, in which the flexibles were bent many thousand times through a right angle at their attachment to a lamp-holder, when under a tension of 3 lbs., and has found that the diminution in section was quite local, and only extended for a very short distance from the point of rupture. This may have been due to the sharp character of the bend in question, and also largely to the fact that the wires are twisted together.

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* *Nuovo Cimento*, vol. 11, series 5, 1906, p. 243.

(2) *Loss of Tenacity due to Increase of Temperature.*—The percentage diminution of the tenacity of copper with increase of temperature is given in Table VI.

TABLE VI.

Diminution of Tenacity of Copper with Increase of Temperature.

Temperature in Deg. Fahr.	Loss of Tenacity Per Cent.
68	2
138	5
248	10
328	15
418	20
438	22
488	25

The temperature attained in lamp-holders is very much higher than is generally supposed. It is, of course, a very variable quantity, depending, not only upon the heat radiated and conducted from the lamp itself to the holder, but also upon the nature of the contact between the lamp terminal plates and the spring plungers of the holder. The temperatures given in Table VII. were kindly measured for the author by Professor W. W. Haldane Gee and Mr. L. Henshaw. They were obtained by means of a thermojunction on lamps and holders in use at the School of Technology, Manchester. The lamps tested were on 110-volt circuits, and the temperatures were taken in two positions, (1) in the lamp-holder between the lamp contact plates, and (2) just above the cord-grip on the flexible.

A further series of tests to determine the temperature attained in bayonet catch holders for electric radiator lamps was made recently by the author and Mr. A. E. Moore for the Engineering Standards Committee on Electrical Plant Accessories, from which the following results are taken :—

Experiments were first made to ascertain the temperature of the outside of the lamp-holder with two lamps glowing. Each lamp took

TABLE VII.

Temperatures attained in Lamp-holders on 110-volt Circuit.

Position I. = Between contact plates of lamp in holder.
Position II. = Just above cord-grip.

Nominal Candle-power of Lamp.	A = without Shade. B = Opal or Bell Shade.	Total Temperature in Degrees F. Room Temperature = 60° F.	
		Position I.	Position II.
8	Mean of five experiments, A	113	96
8	Mean of five experiments, B	118	—
16	Mean of three experiments, A	143	103
25	One experiment (old lamp), A	203	160
50	One experiment, B	329	145
45	Tantalum lamp, "Sun" type	135	108
23	Tantalum lamp, Type H	123	88
30	Nernst lamp, 1/4 ampere size	145	114

3·5 amperes, and the temperature was measured by means of a thermometer in contact with the holder and wrapped round with tinfoil. The holder was screened from the direct radiation of the lamps by the structure of the radiator, and the maximum temperature attained was 160° F. With a view to obtaining the actual temperatures attained by the contact plungers a new holder was taken, and the

TABLE VIII.

Temperature of Contact Plungers in B.C. Holders for Radiator Lamps. Adapter substituted for Lamp. Room Temperature 14° C. (57° F.). Plungers Oxidised by being held in Bunsen Flame and also Chemically without Heat.

Current in Amperes.		Maximum Temperature attained.	
		° C.	° F.
2·0		42	107
3·5 (normal current)		105	221
*4·3	over	230	415
Solder on junction melted.			
3·8 (plungers oxidised chemically with copper nitrate)	over	230	415
Solder on junction melted.			

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* The contacts were examined, and it was found that the action of the plunger springs had been destroyed.

plungers were oxidised by being held in a Bunsen flame for a few minutes; the temperatures were then taken with a thermojunction. The results given in Table VIII. can only be taken as representing what actually occurred in the particular cases mentioned, as the character of such contact resistances is naturally very variable.

It is probable that the heat of the Bunsen first softened the springs, thus causing a bad contact, which resulted in the complete softening of the springs. The temperature attainable in such a damaged holder may be exceedingly high, owing to arcing at the contacts.

These plunger temperatures are of interest, as the plungers are directly connected to the flexible conductors, and the heat thus carried into the insulation is undoubtedly the cause of many breakdowns in the insulation at the lamp-holder hereinafter referred to, as well as tending to reduce the tenacity of the copper, as shown in Table VI.

3. *Corrosion of the Wires due to Sulphur from the Vulcanising Compound.*—The vulcanising compound is usually put on in two layers, the outer one of which, or "jacket," may contain as much as 10 per cent. of sulphur, while the inner one, which is termed the "separator," may contain as much as 3 to 4 per cent. of sulphur. Then follows a layer of pure rubber tape on the tinned conductors. A reference to Appendix E, which contains a detailed examination of old vulcanised flexibles, shows that in most cases the wires have been blackened by the action of the sulphur, and that in some cases they have been severely injured.

Table IX. shows the percentage reduction in tenacity due to this cause from the experiments of the author and Mr. John Roberts.

The load was applied evenly and at a definite rate by means of a small hydraulic ram. Owing to the varying age of the samples it must not be assumed that the composition of the copper is identical in all cases. Further, it is not improbable that the tin coating which initially existed as a separate covering has diffused into the copper and thus reduced its elasticity.

A consideration of this table shows that the wires insulated with vulcanised rubber have become considerably more brittle than those insulated with pure rubber and within a shorter time.

4. *Corrosion of the Wires due to Chemical Fumes in the Air.*—This is not usually a direct action, particularly in the case of vulcanised rubbers, but takes place in the presence of moisture, which leads first to the deterioration of the insulation, and subsequently to the corrosion of the wires by electrolytic action. In the case of flexibles this action is intensified by the juxtaposition of the conductors and the influence of electric osmosis.

Gymp Flexible.—This is a special flexible which was brought to the author's notice by Mr. Mervyn O'Gorman. Owing to the structure of the conductors it possesses an extraordinary degree of flexibility, and its performance in this respect is referred to under the head of Tests on Completed Flexibles (see page 69). The conductors are composed of flat copper strips, 10 mils. wide and 1·5 mils. thick. These strips are

TABLE IX.

Tensile Strength of Conductors of Old Flexibles Insulated with Pure and Vulcanised Rubber and with Cotton. Length of Test Piece, 7 ins.

Sample.		Diameter of Wire in mm.	Breaking Load in Grammes per sq. mm.	Percentage Extension on Rupture.	Nature of Insulation.
Reference Number.	Age in Years.				
E. 31	7	0·160	18,800	18·3	Pure rubber.
E. 34	20	0·134	17,600	17·2	"
E. 36	10	0·162	20,500	20·7	"
E. 11	14	0·135	18,350	19·5	"
E. 9	22	0·135	23,150	17·0	"
E. 10	18	0·134	19,350	24·0	"
E. 13	16	0·126	20,000	14·3	Cotton only.
E. 42	6	0·150	20,300	10·3	V.I.R.
E. 17	7	0·159	20,900	11·5	"
E. 8	8	0·134	14,200	0·9	"
E. 41	8	0·134	20,350	10·0	"
No. 40, S.W.G. New copper wire, untinned		0·125	24,900	24·5	—
No. 36. New copper wire, tinned ...		0·195	24,150	24·9	—
Ditto		0·200	24,180	26·3	—

NOTE.—The breaking load per sq. mm. is calculated on the measured diameter of the wires, and therefore includes the tinning.

each wound in a close spiral around a separate silk core, and twenty-one of these are then stranded together in sets of seven to form the complete conductor. The resistance of such a conductor is naturally high, that of the small specimen submitted to the author after it had run 1½ million times over a counterweight pulley being 1·72 ohms per yard of double conductor.

In general the question of conductivity of flexibles as applied to pendants, etc., may be considered as being overridden by the requirements of mechanical strength, which will dictate the minimum section to be employed, but the conductivity is of considerable importance in connection with the use of flexibles for wiring systems.

III. HEATING OF CONDUCTORS DUE TO EXCESSIVE CURRENTS.

This matter is of interest in connection with the temperatures attained with flexibles due to short-circuit currents and the employment of heavy fuses on sub-circuits.

A series of experiments was made by the author and Messrs. F. Shaw and J. Davies on (1) the temperatures attained in a given time with bare conductors with various currents, (2) the corresponding temperature rises with the same conductor when insulated. The results of these experiments are shown graphically in Figs. 4 and 5. As is to be expected, the temperature rise in a bare wire with a given current is higher than that of the same wire when insulated. The currents selected were purposely large in order that the kindling point of the insulation might be reached. It is to be noted that in Fig. 4 the conductor was only covered by the insulation, there being no braiding or other covering over this; in consequence the rubber did not take fire, but merely melted off. Further, these tests were designed to show the temperatures attained with comparatively large currents of short duration, and they must not be taken as indicating the temperatures attainable with the currents named if kept on continuously.

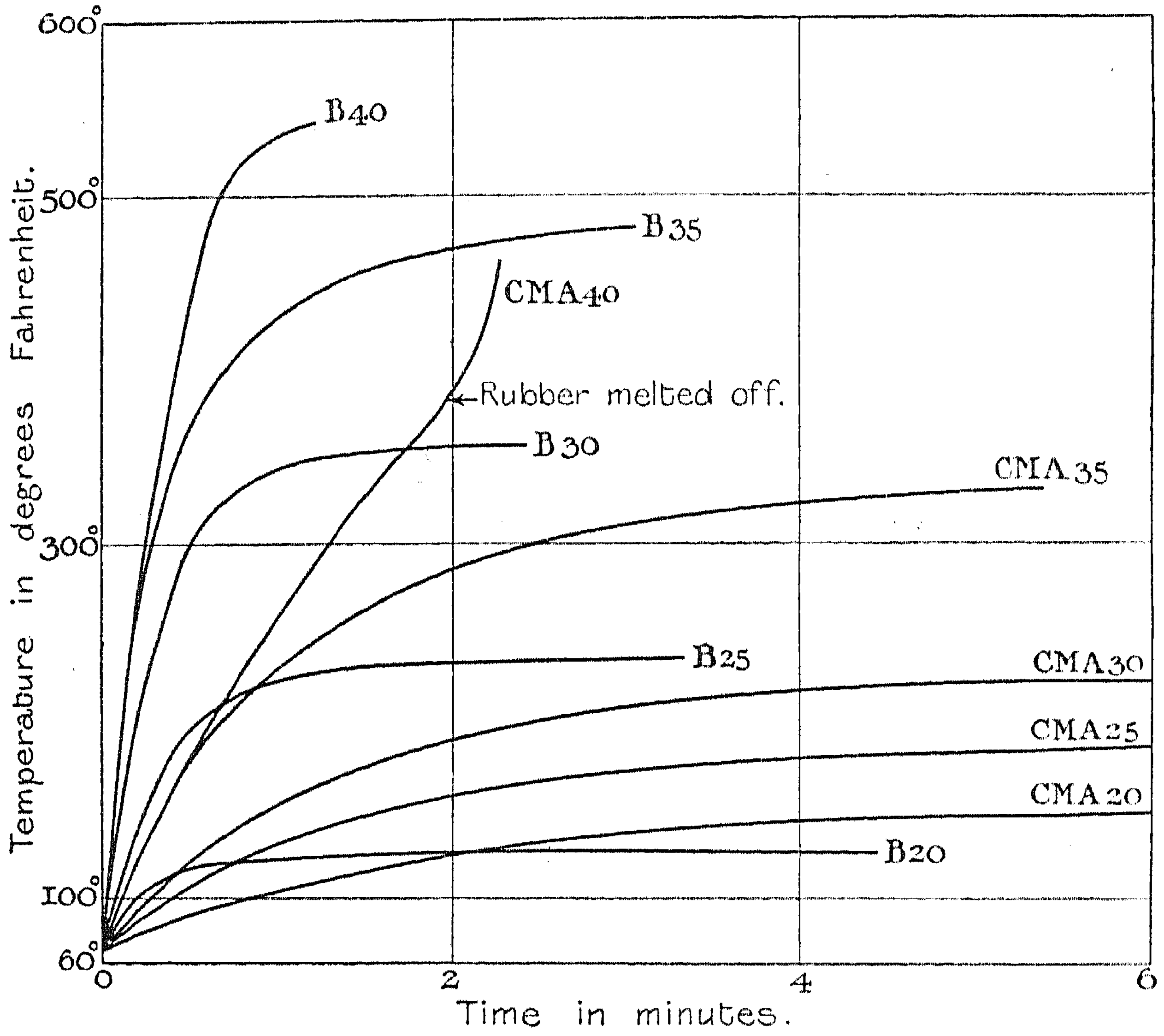

FIG. 4.—Temperature Rise on 23/36 Conductor with Currents of 20, 25, 30, 35, and 40 Amperes.

B. = Bare Wire.
C.M.A. = Cable Makers' Association V.I.R. Covering only without Braiding.
Room Temperature, 60° F.

Fig. 5 shows the relative temperature rise on a 23/36 conductor with a given current when made up in different forms. A consideration of these curves shows that there is not much to choose between the various finishes tested as to their radiating capacity.

A further series of experiments was carried out with the same size of conductor in various finishes but with heavier currents, with a view to finding the kindling point of the insulation. The results are given in Table X. They are remarkable in that with one exception they show that the vulcanised rubber insulation actually burst into flame only when the conductor fused. This is doubtless due to the firing of the inflammable vapours by the arc following the fusion of the conductors, and it is rather an unfortunate property from a fire risk point of view, as it may start the fire from two centres, one on the floor beneath and the other on the ceiling above. Flexibles insulated with pure rubber ignite before the wire fuses. The proportion of rubber in vulcanised indiarubber compound is comparatively small, and the mineral loading matter evidently delays the ignition.

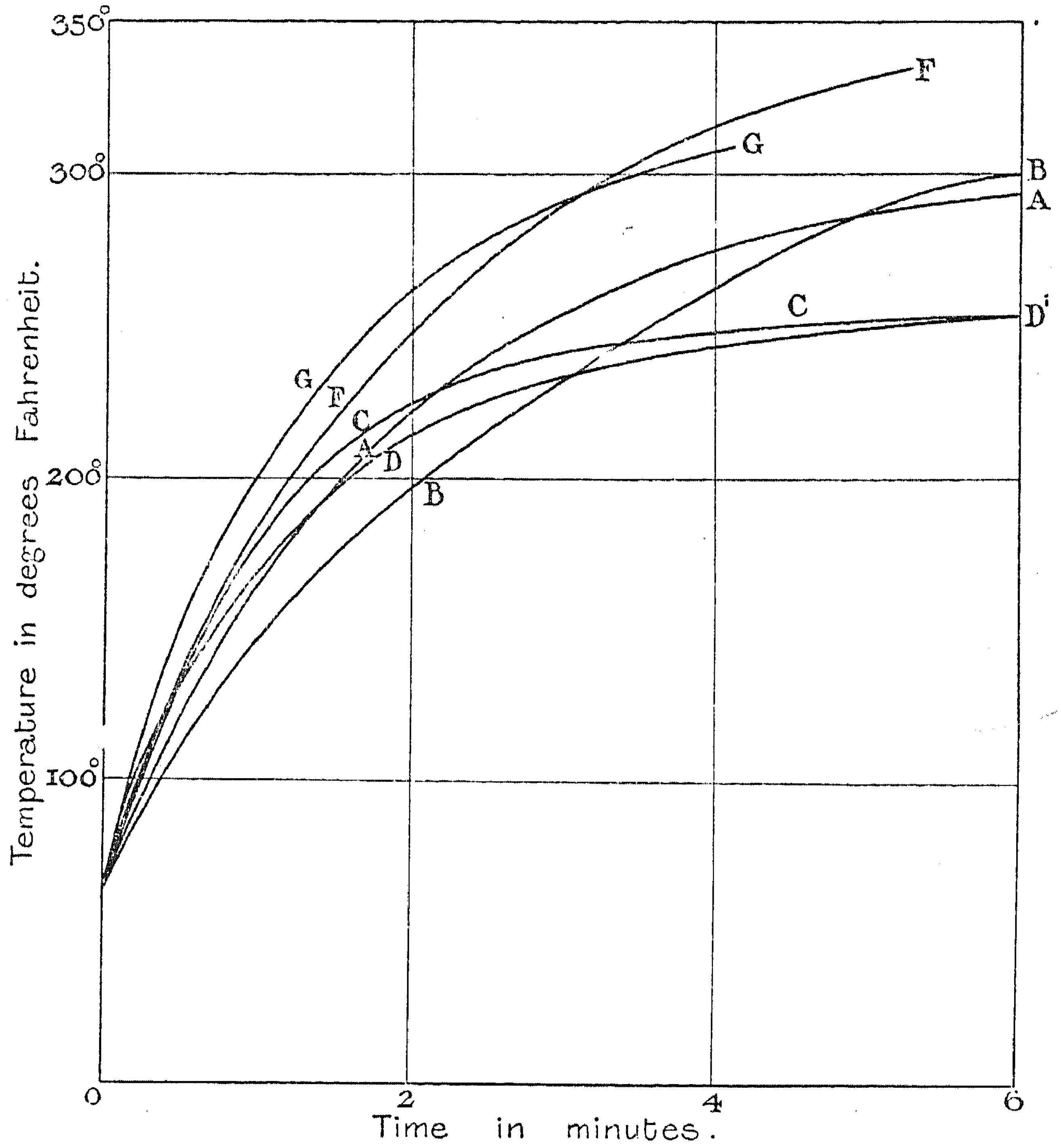

FIG. 5.—Temperature Rise on 23/36 Conductor in various Finishes with a Current of 30 Amperes.

A = C.M.A. Twin-twisted Glacé.
B = C.M.A. Workshop.
C = C.M.A. same as A, but Single Conductor.
D = C.M.A. Twin-twisted Silk.
F = Double Pure Rubber Twin-twisted.
G = Single Pure Rubber Twin-twisted.

These experiments were for obvious reasons conducted in a fume chamber, where the air was comparatively still, and it is possible that in a strong current of air the ignition of the vulcanised indiarubber might take place before the fusion of the wire; but the general result, that in still air the insulation will give off heavy fumes but will only smoulder and char while the conductor remains intact, is supported by the fact that the persistent arcs which have already been referred to travel up these wires without flaming.

TABLE X.

Kindling Points of Flexibles.

The Times given are from the Moment of Switching on the Current. With Currents of 40, 50, 60, and 70 Amperes. Time in Minutes and Seconds.

A. INSULATED WITH VULCANISED RUBBER.

Condition of Insulation.	C = 40.		C = 50.		C = 60.		C = 70.		Description of Flexible.
	Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Smoking	1	55	0	40	—		—		Twin-twisted 23/36 C.M.A.
Insulation melting out	3	0	1	20	0	40	0	30	
Dense fumes ...	5	0	1	45	1	0	0	35	
Material red hot ...	6	0	2	0	1	3	0	44	
Fused	7	5	2	28	1	30	1	1	
Flamed			2	25					
Smoking	4	0	1	30	0	35	—		Workshop 23/36 C.M.A.
Insulation melting out	4	30	1	45	0	40	—		
Dense fumes ...	6	0	2	20	1	15	—		
Material red hot ...	8	40	2	50	1	30	—		
Fused and flamed	8	45	3	20	1	40	—		
B. INSULATED WITH PURE RUBBER.									
Smoking	1	25	0	40	0	20	0	10	Twin-twisted 23/36 single pure rubber.
Dense fumes ...	1	40	0	50	0	25	0	20	
Material red hot ...	2	10	1	5	0	35	0	30	
Flamed	2	18	1	10	0	40	0	33	
Wire did not fuse	5	0	—		—		—		
Wire fused ...	—		1	15	0	45	0	36	
Smoking	2	0	1	10	0	35	0	15	Twin-twisted 23/36 double pure rubber.
Dense fumes ...	2	30	1	15	0	40	0	25	
Material red hot ...	3	20	1	30	0	50	0	40	
Flamed	3	40	1	50	1	0	0	45	
Wire fused ...	—		2	0	1	5	0	47	
Wire did not fuse	6	0	—		—		—		

IV. Insulation of Flexibles.

Before dealing in detail with the insulation of flexibles it will be well to consider briefly the prominent characteristics of the materials employed. This procedure is doubly desirable, first on account of the secrecy observed with regard to rubber manufacture, which entails an almost complete ignorance on the part of the average electrical engineer of the character of this important material, and secondly because it is necessary that those who are actively concerned with the employment of the material in practice should be in a position to judge for themselves of the results of tests that may be submitted to them or which they may specify or carry out.

Pure Rubber Strip.—The pure rubber strip which is used for insulation purposes is prepared by two distinct methods, and is known as "cut" or "spread" sheet, according to its mode of manufacture.

The raw material is the same in either case, and is first washed and dried. In the preparation of "cut" strip the dried rubber is, after being passed through compression rollers, put through a "masticator" and then formed into blocks under considerable pressure. These blocks are frozen hard and then cut into sheets by special machinery. The process outlined above is necessarily expensive, and is only followed by a few firms in this country.

The manufacture of "spread" sheet is much simpler and less costly. The dried rubber is made into a paste or "dough" by means of a solvent and is then spread on to a length of cloth. The solvent is then driven off by heat, leaving the rubber in the form of a sheet, which is then cut into strip.

On the Continent, owing to the cost of fine Para rubber, foreign material is added with a view to producing a cheap article which is put on the market as second or third quality sheet. "Cut" strip is generally used in this country for the innermost layer in high-class cable work, while "spread" strip is very largely used for rubber-taped flexibles, insulating tape, etc.

The "spread" sheet should, in order to have the requisite mechanical and electrical properties, be "aged" by hanging in a dark room for several months.

The strip may be artificially aged or cold vulcanised by treating the surface with a solution of chloride of sulphur in carbon bisulphide. As rubber tape is often used next to the copper conductors it is important that it should not contain sulphur. This cold vulcanised strip not only contains sulphur but nearly always contains hydrochloric acid as the result of its chemical treatment.*

Pure rubber has a great affinity for oxygen, and if placed in direct contact with copper, the latter will part with any oxygen it has to the rubber; it is therefore quite necessary that the wires should be tinned or at least covered with a close wind of cotton when in contact with pure rubber.

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* Atkinson and Beaver, "Some Points on the Selection of Electric Light Cables," Manchester Local Section, I.E.E., 1905; *Electrician*, vol. 54, p. 702.

Absorption of Water by Indiarubber.—The classic experiment of Thomas Hancock, which extended over a period of thirty years—from 1826 to 1856—showed that water hermetically sealed in a rubber bag is capable at ordinary atmospheric pressure of passing through rubber, the whole of the water contained in the bag—rather more than 12 oz.—having disappeared in that time.

Indiarubber will absorb about 25 per cent. by weight on prolonged immersion in water with considerable increase in volume.

The amount of water absorbed is a very variable quantity, and depends very largely on the amount of oily and resinous matter contained in the rubber and also on the treatment that its surface has received.

This question is of importance in connection with flexibles insulated with pure rubber, particularly as under the action of electric osmosis the moisture of the positive conductor may be driven over and forced into the negative insulation.

Vulcanised rubber is much more homogeneous in structure than pure rubber, and the amount of water absorbed is, in consequence, very much less, but nevertheless the fact that it does absorb water must not be ignored. A reference to the Appendices A, B, and C at the end of the paper will show that immersion tests for flexibles are required in the United States (A. 2*d*), in Germany (C. 2*d*), and in France (B. 1*c*).

The insulation resistance after immersion in water may be taken as an indication of the amount of absorption of water by V.I.R. flexibles, but can hardly be so taken when pure rubber tape is employed, as the water may enter between the joints. A well-made pure rubber flexible will stand immersion in water without actually breaking down for a much longer period than is generally supposed. Mr. Lester Taylor informed the author that he had a short length immersed in water which supplied current to a 100-volt lamp for several months without breakdown. The following tests were made on vulcanised (600 megohm grade) and double pure rubber (2,000 megohm grade), supplied by Firm C, immersed in water for a week at 60° F.

Double pure rubber. Test pressure, 550 volts.

Insulation between conductors: In air, 6,000 megohms; after one week in water at 60° F., 40,000 ohms.

On immersion in water the insulation fell almost at once to 80 megohms, and thence slowly declined and broke down in eight days with 400 volts. This test was on a length of only 10 yards.

Vulcanised rubber. Result of immersion inappreciable on 10-yard length.

Vulcanised Rubber.—Of all the constituents of manufactured indiarubber none possess such a paramount influence upon the general excellence of the product as the sulphur of vulcanisation. The amount of sulphur employed in practice varies greatly from 4 up to 50 per cent., but the amount of sulphur fixed by the indiarubber (sulphur of vulcanisation) very rarely exceeds 3 per cent. in commercial rubber articles, and is generally less. Free sulphur in various proportions always forms a constituent of ordinary vulcanised indiarubber goods. C. O. Weber* states that the percentage of combined sulphur is no measure of its degree of vulcanisation, and instances the following analysis of the outer cover of a tire:—

Indiarubber	54·70 per cent.
Organic extract	1·34 "
Sulphur of vulcanisation	1·99 "
Free sulphur	2·88 "
Total mineral matter	41·08 "

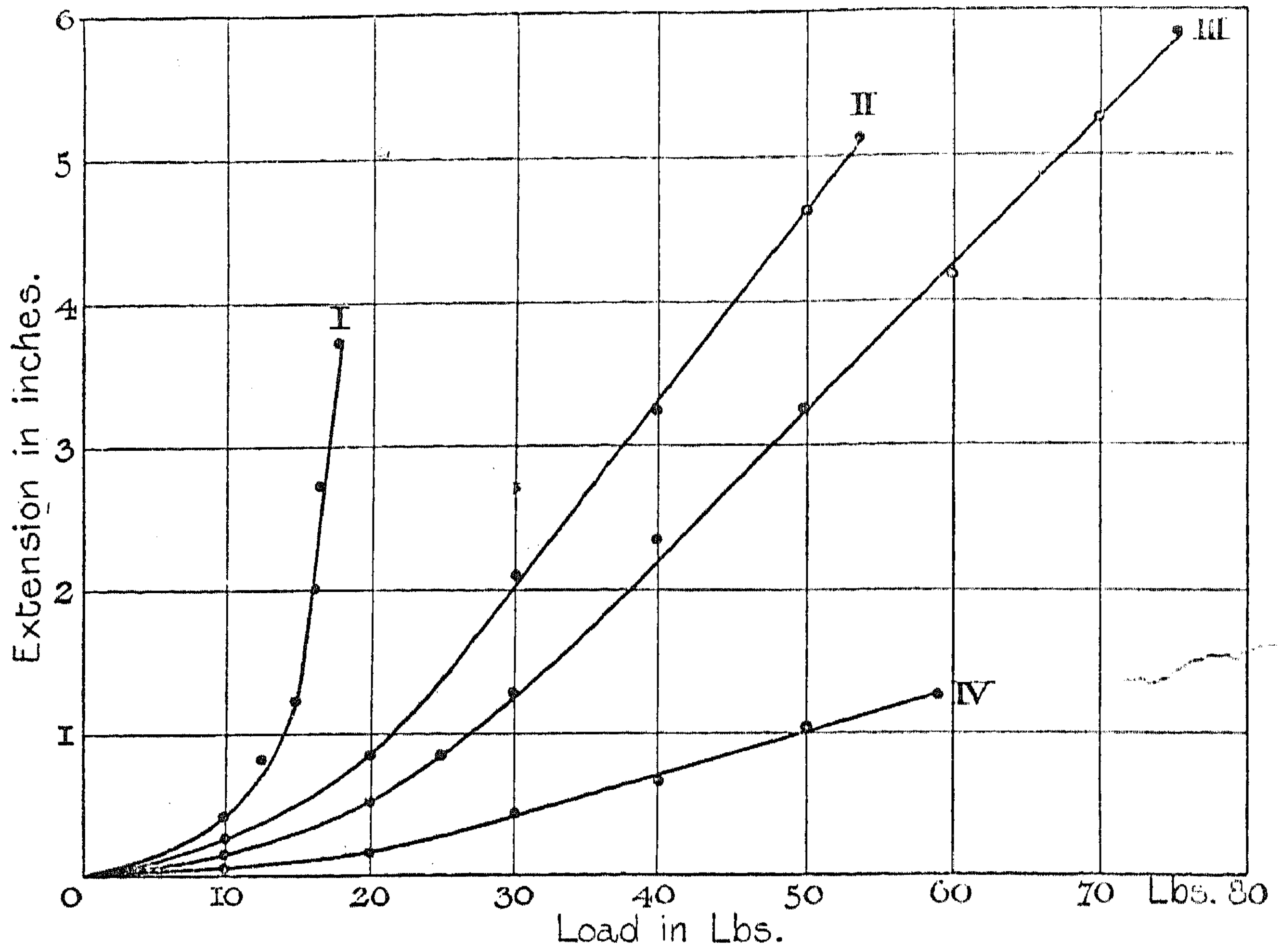

FIG. 6.—Tensile Strength of Differently Vulcanised Specimens of Para Rubber.

SAMPLE.	VULCANISATION COEFFICIENT.
I.	1·78 per cent.
II.	2·14 "
III.	2·87 "
IV.	4·44 "

He obtains the degree of vulcanisation by calculating the percentage ratio between the amount of indiarubber and sulphur of vulcanisation present. Thus from the above analysis—

$$\text{Coefficient of vulcanisation} = \frac{1·99 \times 100}{54·7} = 3·63 \text{ per cent.}$$

As the coefficient of vulcanisation is increased, the tensile strength, elasticity, and distensibility are up to a certain point also increased; beyond this point there is first a rather rapid decrease in elasticity and distensibility, followed soon by a decrease of tensile strength. Fig. 6

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[*] "The Chemistry of Indiarubber," London, 1902, p. 283.

(C. O. Weber) shows the elongation and tensile strength of four tire covers of absolutely identical composition as regards the quality and proportions of Para rubber, total sulphur, and mineral matter, but cured under different conditions.

Of these samples I. and II. are under-vulcanised, III. is satisfactory, while IV. is over-vulcanised. It will be seen from a consideration of Fig. 6 that the higher the coefficient of vulcanisation the higher is the tensile strength for the same elongation. The results given are typical for Para rubber.

Over-vulcanisation does not consist simply in a high coefficient of vulcanisation, but in one obtained under unsuitable conditions, either of temperature, or of time, or of quantity of sulphur. Of these causes too high a temperature is the commonest one, while too short a time is the most usual cause of under-vulcanisation. Flexibles as a rule are slightly under-vulcanised, as it is found that a few minutes more or less in the vulcanising chamber may make the difference between a bright or blackened conductor.

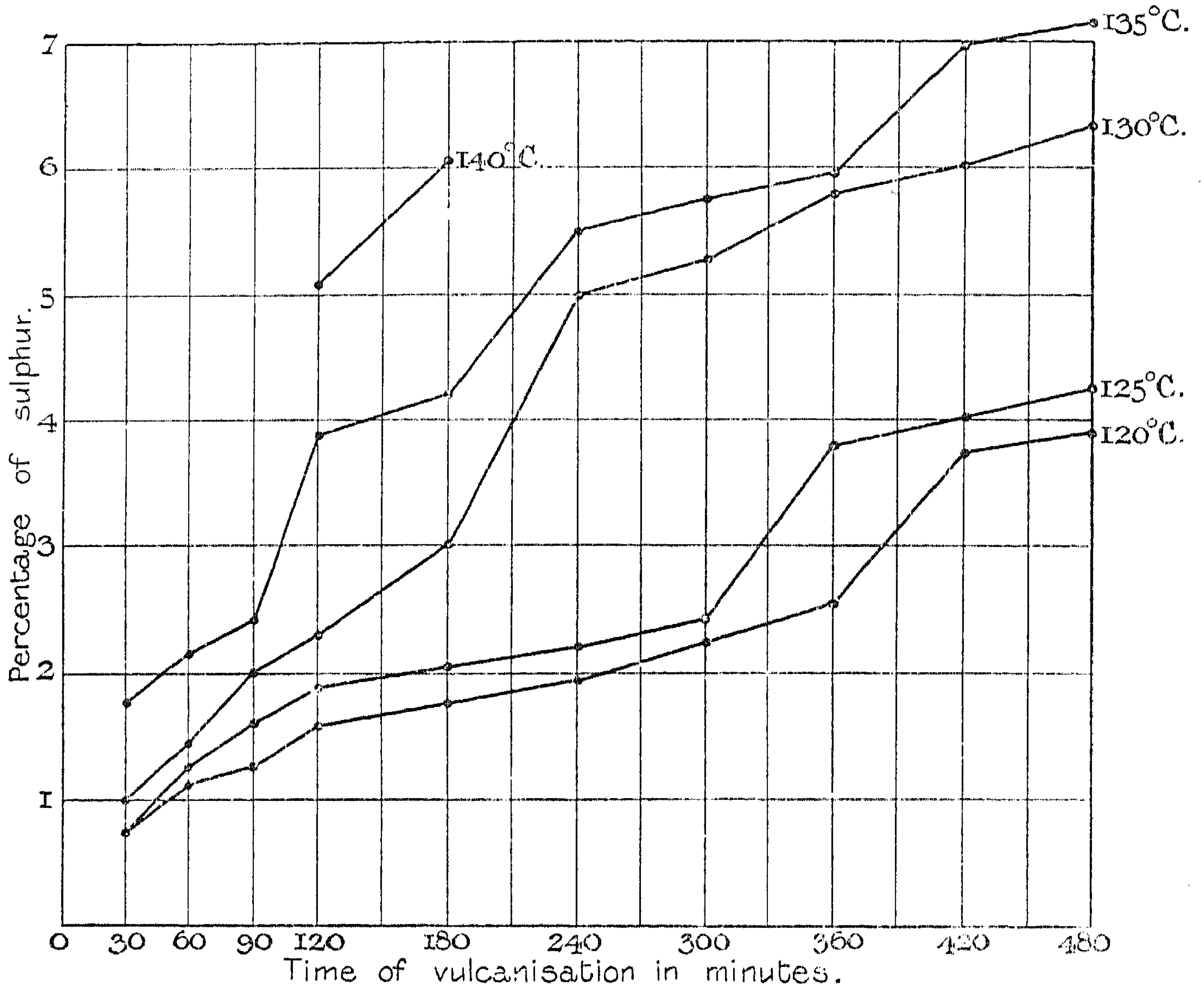

FIG. 7.—Vulcanisation Curves of Para Rubber at Different Temperatures.

The rate at which the sulphur enters into combination with the indiarubber hydrocarbon (polyprene) is characteristic for each brand of rubber. Fig. 7 (C. O. Weber) shows the vulcanisation curves for Para rubber.

The experiments were carried out with strips cut from a calendered sheet 3 mm. in thickness from a mixing of 100 parts of Para rubber with 10 parts of pure precipitated sulphur. After vulcanisation in a digester the samples were freed from every trace of uncombined sulphur by extraction with acetone in a Soxhlet extractor, and the sulphur of vulcanisation subsequently ascertained by analysis. This point is of interest in connection with the high temperatures attained in lamp-holders and the possibility of the free sulphur present entering into combination with the rubber and producing an over-vulcanised covering.

V. OXIDATION OF RUBBER.

The formation of resinous bodies from unvulcanised rubber on exposure to the air was first observed by Spiller.* These oxidation products are known as Spiller's resin. Burghardt† states that the amount of oxygen taken up or combined with the rubber is an index of the amount of deterioration which it has undergone, and quotes the analysis given in Table XI. in support of this view.

TABLE XI. (BURGHARDT).

Oxidation of Rubber as an Index to Deterioration.

	Sample Number.				
	1.	2.	3.	4.	5.
Carbon	87·27	87·50	77·91	72·53	64·00
Hydrogen ...	12·73	10·00	10·33	11·31	9·26
Sulphur	Nil	2·50	5·12	1·97	2·28
Oxygen	Nil	Nil	6·61	14·19	24·46

No. 1. Pure caoutchouc from Para.
No. 2. Theoretically vulcanised elastic thread.
No. 3. Vulcanised elastic thread perfectly sound.
No. 4. Vulcanised elastic thread damaged, but still elastic.
No. 5. Vulcanised elastic thread brittle and very hard.

Thomson,‡ who investigated the subject, further observed marked oxidation, especially at higher temperatures.

A consideration of Appendix D, which contains a detailed examination of samples of flexibles which have been in use for a number of years, shows that the vulcanised rubbers seem to have suffered most, but that the pure rubber also has in many cases perished considerably. This perishing, due to oxidation, although it no doubt takes place more rapidly in the high temperatures in the immediate vicinity of the lamp-holder, and to a lesser degree at the ceiling rose also, affects the whole of the cord, and in the author's view puts a limit of from ten to twelve years as the safe life of an average flexible of good quality under favourable circumstances. The use of oxidised oil, recovered rubber, and other rubber substitutes will shorten the life of the flexible in proportion to the quantities of these substitutes that are present.

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* *Journal of the Chemical Society*, vol. 3 (new series), 1865, p. 44.
† "Thorpe's Dictionary of Applied Chemistry," vol. 2, p. 320.
‡ *Journal of the Society of Chemical Industry*, vol. 4, 1885, p. 710.

There is no doubt that oxidation plays a prominent part in the deterioration of flexibles in warm situations, and it would be interesting to know if the "reinforced cord" used in the United States—consisting of a filling of rubber or bitumen which makes up the cord to circular form and completely encloses the insulated conductors—conduces to the longer life of the actual insulation by excluding the oxygen.

Recovered Rubber.—Recovered rubber undergoes vulcanisation just like fresh rubber, but it is not devulcanised by the recovery process; indeed, the sulphur of vulcanisation is increased rather than lessened. Consequently samples containing a large percentage of recovered rubber have usually a high coefficient of vulcanisation, so that if the hysteresis loops (Figs. 10–13) or the elongation tests do not point to over-vulcanisation, this high coefficient may usually be taken as indicating the presence of recovered rubber. This is not always the case, as the recovered rubber may have been prepared from articles having a low coefficient of vulcanisation.

VI. Effect of High Temperature on Rubber.

The high temperatures attainable in lamp-holders have already been discussed. Under the influence of high temperature rubber develops many defects, of which the following are the chief :—

(1) *Loss of strength or cohesion.*
  Rubber with a comparatively low coefficient of vulcanisation is liable to develop this defect, particularly if the time for vulcanisation has been short, as is not unusually the case with flexibles.

(2) *Hardening with brittleness.*
  This defect appears in rubbers containing white substitutes (chlorosulphides), but more commonly is due to the presence of a considerable amount of free sulphur.

(3) *Stickiness and darkening in colour.*
  This defect is associated with rubbers containing mineral oils, large quantities of recovered rubber, or large proportions of sulphide substitutes.

In order to test the effect of high temperature on pure and vulcanised rubbers, the following experiments were carried out by the author and Messrs. Roberts and Davies. A number of samples of vulcanised rubber were cut from wire supplied by Firm D. These were about 3 ins. long, and were placed in an electrically heated oven and kept continuously at a temperature of 100 to 105° C. Three samples were withdrawn each day, and tested, for breaking load and extension. As may be anticipated, it was found that the pure rubber was quite unable to withstand this temperature, and melted. The vulcanised rubber rapidly deteriorated both in tensile strength and percentage elongation. The results of these tests are shown graphically in Figs. 8 and 9.

A further series of deterioration tests on C.M.A. vulcanised rubber was carried out at 100° F., but did not yield consistent results. The tests were therefore repeated at 150° F., and the results are shown graphically in Fig. 9A, the points plotted being in each case the mean of three experiments. The rise in Curve A is curious; it was found that this same material, when sealed up in glass tubes filled with carbon dioxide and maintained at 150° F., had at the end of four days a percentage extension of 550 as against an initial value of 450, while at the end of twelve days it had only fallen to 400, and throughout the test the breaking stress remained constant at 960 lbs. per square inch. Firm C's samples (see Curves C and D, Fig. 9A) when heated in carbon dioxide under the above-mentioned conditions had an initial breaking stress of 1,280 lbs. per square inch, which fell at the end of twelve days to 960 lbs., and in the same period the percentage extension decreased from 500 to 400. In these cases three experiments were made for each

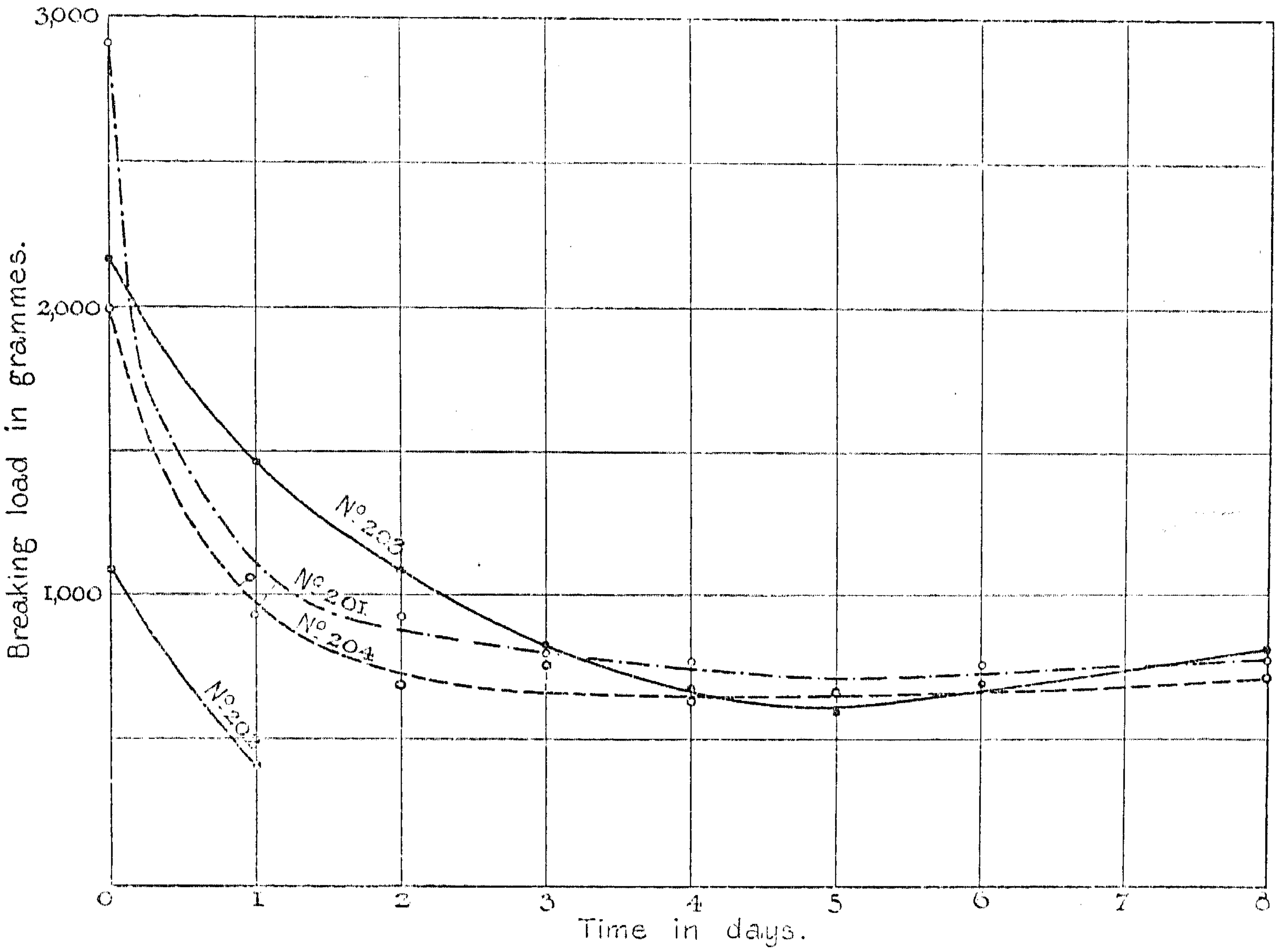

FIG. 8.—Effect of Heat on Tensile Strength of Vulcanised Rubber.
Reference No. 201–4. Heated in Air for 8 Days at 100–105° C. Length of Test Piece, 1·8 cms.

point, and gave very consistent results, but a fuller knowledge of the constituents of the compounds is required to interpret them correctly. A consideration of Curves in Figs. 8, 9, and 9A, together with the results of heating in carbon dioxide, would appear to indicate that:—

(1) The greater part of the deterioration is due to oxidation.
(2) A certain amount of deterioration goes on in the absence of oxygen, and possibly some change in the state of the vulcanisation may take place.

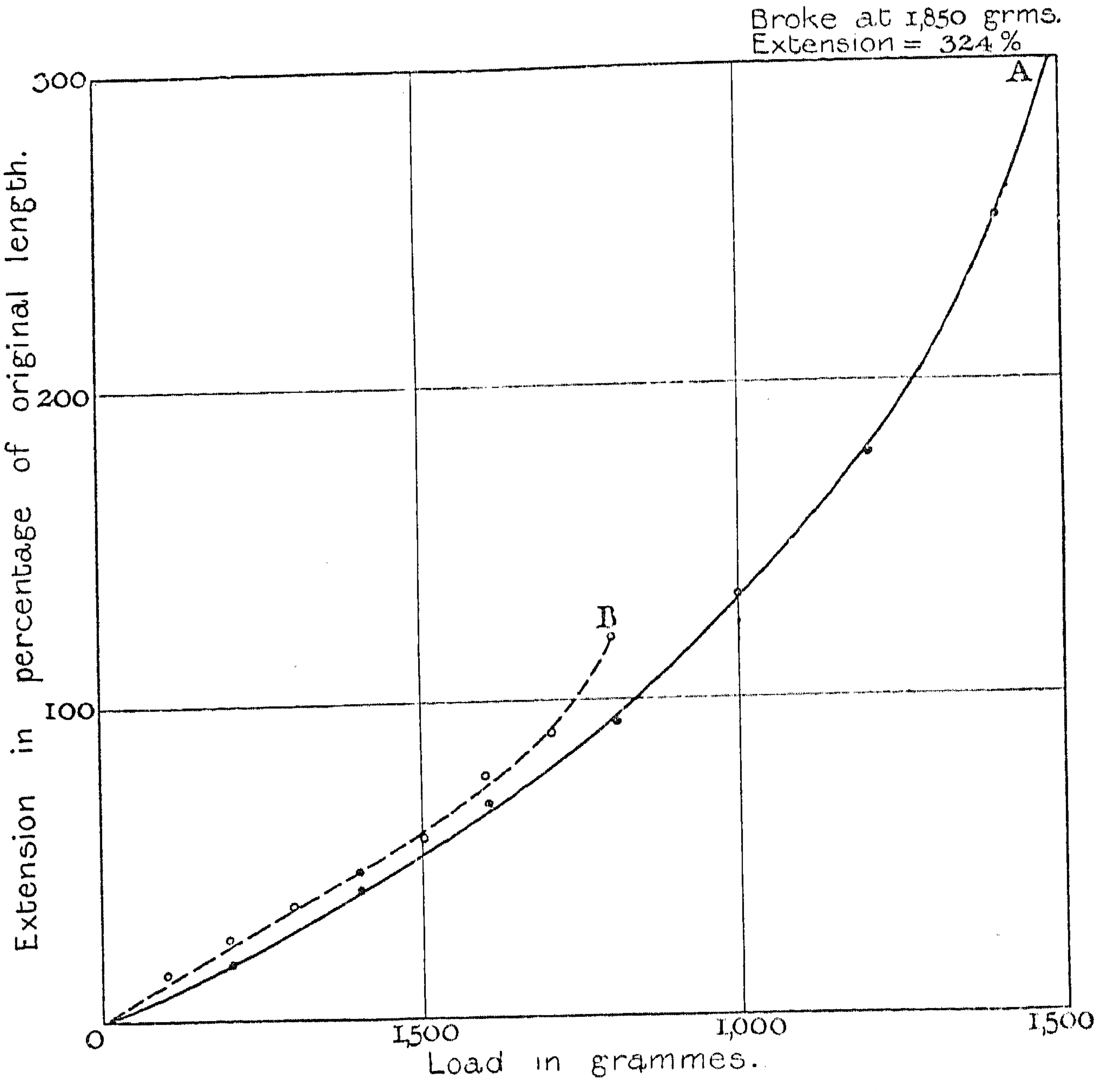

Fig. 9.—Effect of Heat on Vulcanised Rubber.

Reference No. 203. Curve A, Percentage Extension of New Sample at 60° F. Curve B, Extension of Sample of Same Material after Heating in Air at 100° C. for 8 Days.

(3) Although the rate of deterioration is fairly constant over a considerable period, it would be advisable to extend the dry heat test over a longer period than one hour, which is the present practice.
(4) An extension test after a period of heating at 150° F. is desirable to discriminate as to the probable durability of the materials employed.

The question as to which of the two classes of rubber gives the best results in such a high temperature is a debatable one. The author favours the view that pure rubber is best suited for high temperatures, since if it does soften and melt, it is absorbed by the cotton surrounding it, whereas in the case of vulcanised rubber it becomes hard and friable and disintegrates on bending.

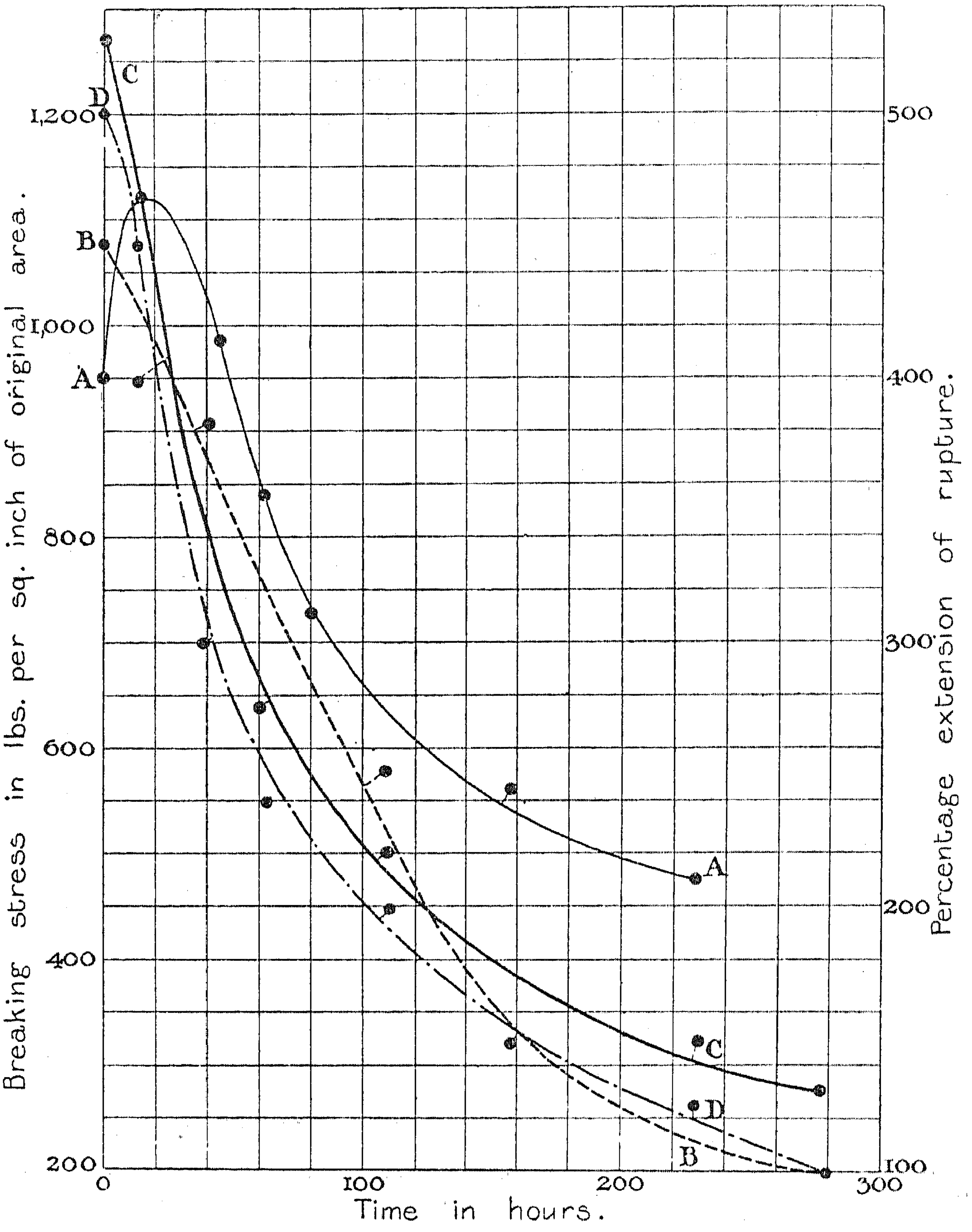

Fig. 9a.—Effect of Heating Vulcanised Rubber at 150° F.

Curve A, Breaking Stress C.M.A. Flexible, Firm D.
" B, Percent. Extension " " "
" C, Breaking Stress " " Firm C.
" D, Percent. Extension " " "

VII. Hysteresis of Rubber.

J. C. Shedd and R. L. Ingersol,* experimenting with rubber bands, found on gradual stretching and releasing that if the extensions and retractions are plotted on a base of load, a complete hysteresis loop is obtained. They investigated the elastic limit of rubber, but the data attached to their curves are incomplete, so they are not reproduced here.

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* *Physical Review*, vol. 19, 1904, p. 107.

The following experiments on the mechanical hysteresis effect in pure and vulcanised rubbers were carried out by the author and Mr. R. K. Keer. The rubber to be tested was in the form of strip, and was suspended from a clip and loaded directly by means of weights; the length between two marked points was measured on a vertical glass scale behind the rubber. Throughout the experiments the room temperature was 61° F.

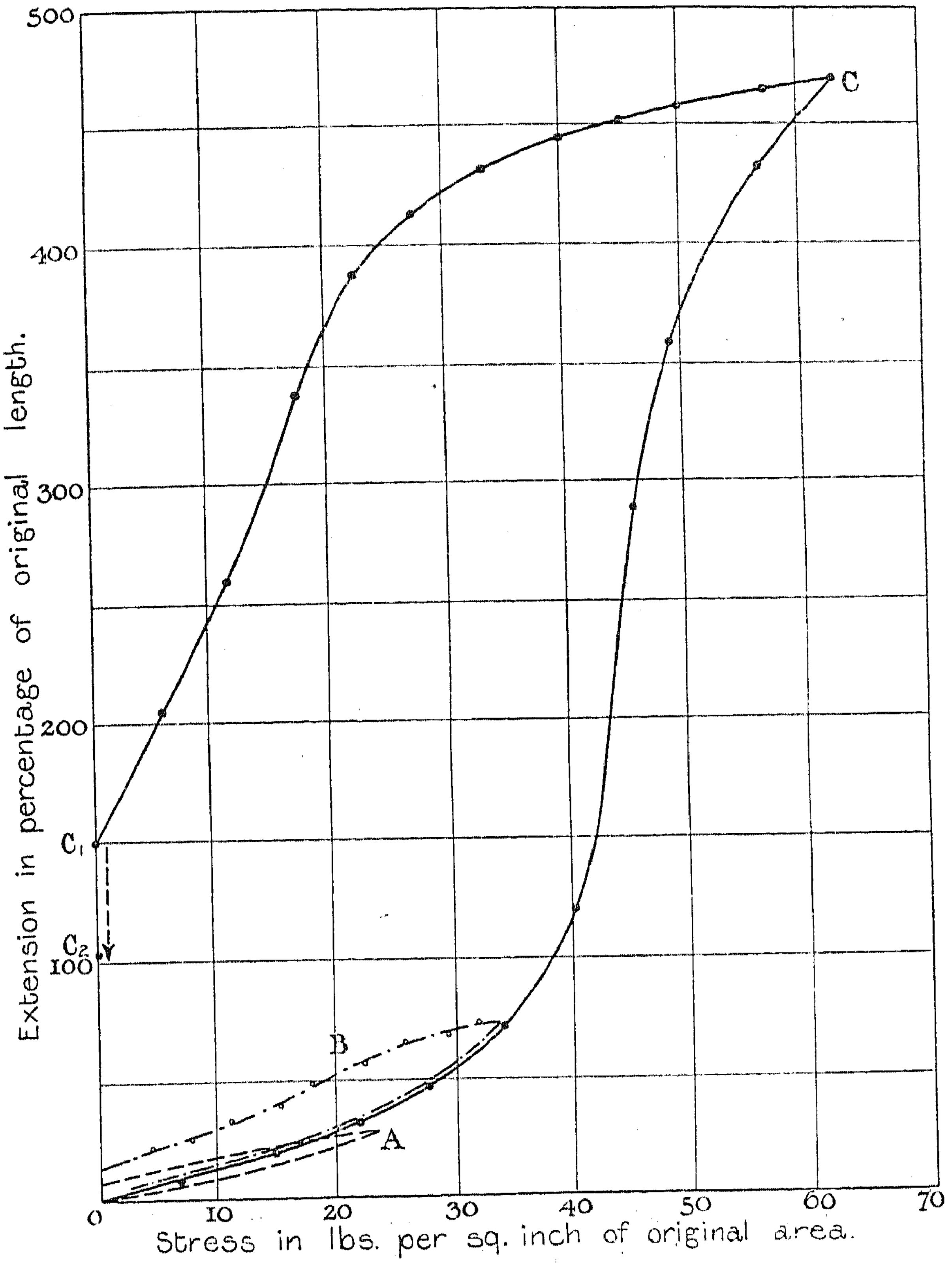


FIG. 10.—Hysteresis Curves for Pure Spread Rubber Sheet. Width, 0·71 in. Thickness, 0·025 in.

A. Length, 7·88 ins. Time between applying Load and taking Reading = 30 seconds.
B. „ 7·88 „ „ „ „ „ „ „ = 2 minutes.
C. „ 1·97 „ „ „ „ „ „ „ = 2 „

Tests were first made on commercial pure rubber strip, as used for insulating purposes; this strip is prepared by the spreading method, The results are shown graphically in Fig. 10. Curve A was obtained on a 20-cm. length, the readings of the extensions being taken thirty seconds after adding or subtracting the loads. Curve B was obtained on the same piece of rubber used for Curve A, the readings in this case being taken after a lapse of two minutes; the load also was carried to a higher value. It is evident from a consideration of these curves that with low loads the hysteresis effect is small, and that the time (between the limits named) allowed to elapse between the alteration of the load and the reading of the extensions does not affect the results to any great extent. With large loads, however, this time lapse is very important, as the rubber flows considerably. In all the following experiments a two-minute interval was allowed. Curve C, Fig. 10, shows the loop obtained with strip of the same dimensions as in A and B, but with the stress increased nearly to the breaking-point of the rubber. The ordinate OC_1 represents the "permanent" set in the rubber. This is really a very variable quantity, as rubber possesses considerable power of recovery; in this instance OC_2 represents its value after a lapse of sixteen hours.

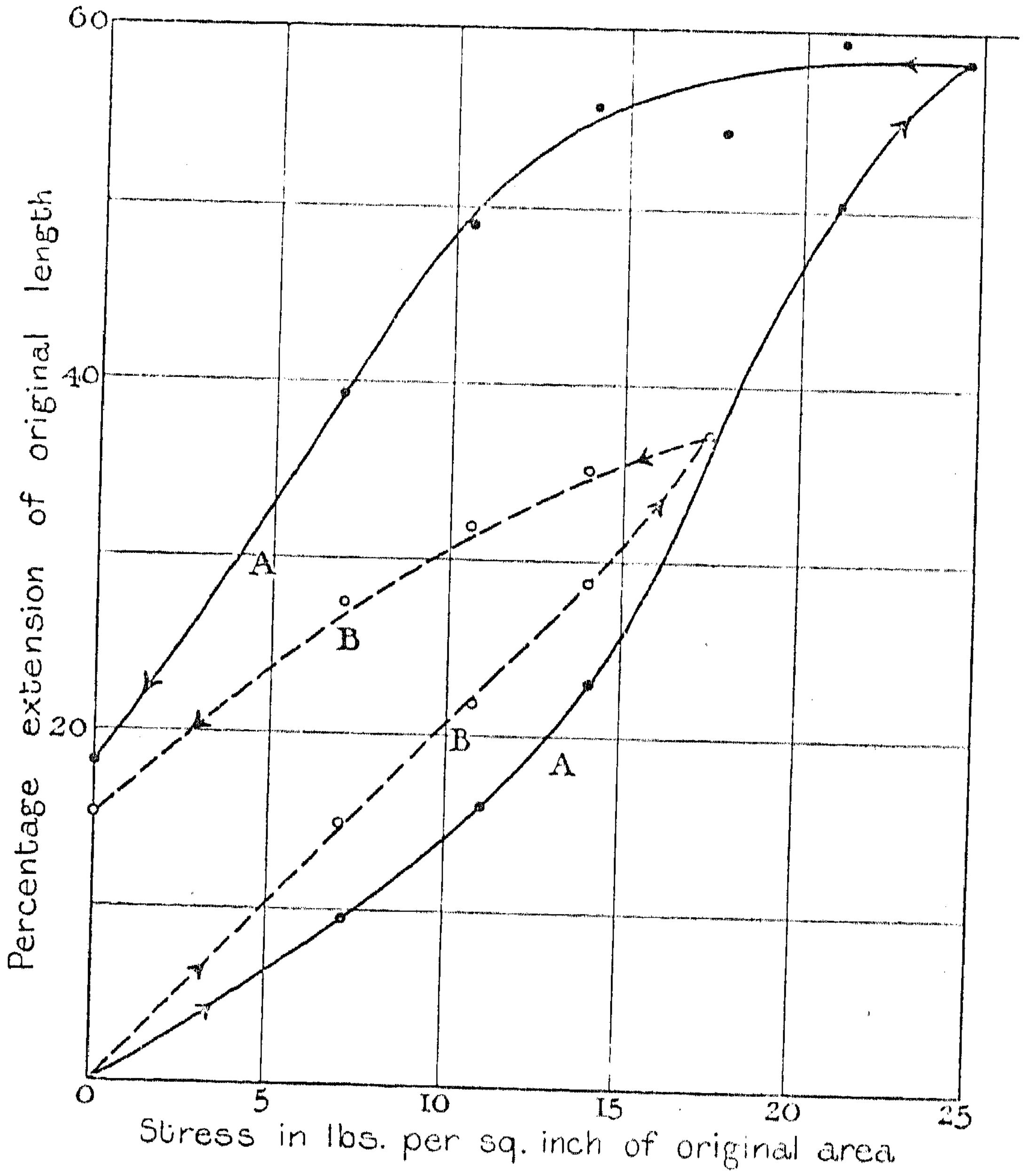


FIG. 11.—Hysteresis Curves for Pure "Cut" Rubber Strip. Width, 0·39 in. Thickness, 0·036 in.

A. Length, 0·39 in. Tested with the Grain.
B. ,, 1·97 ,, ,, across ,, ,,
Room Temperature, 60° F.

Fig. 11 shows the results obtained with "cut" strip. This material possesses very different tensile strength according as it is tested with the grain or across the grain, the "grain" being due to saw marks in cutting. Curve A is for "with the grain" and B for "across the grain."

Experiments were made on C.M.A. vulcanised rubber stripped from flexibles supplied by four separate firms.

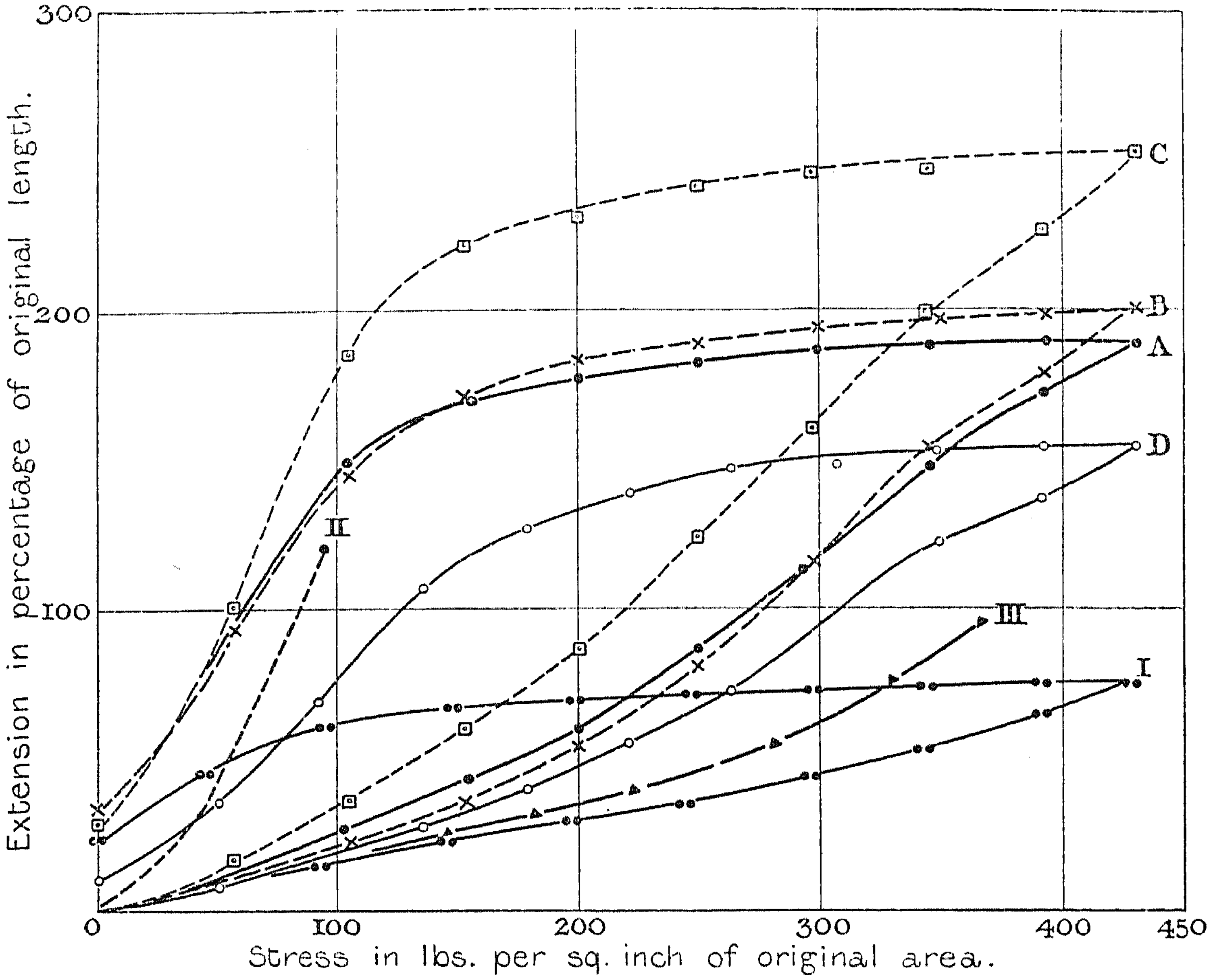


FIG. 12.—Hysteresis Loops for C.M.A. Flexibles 40/36.

A = Firm A, Breaking Load 590 lbs. per sq. inch. % Extension on Rupture 375.
B = ,, B ,, ,, 440 ,, ,, ,, ,, ,, ,, ,, 325.
C = ,, C ,, ,, 440 ,, ,, ,, ,, ,, ,, ,, 325.
D = ,, D ,, ,, 650 ,, ,, ,, ,, ,, ,, ,, 366.

Samples sold as being equal to C.M.A. Insulation (I.) and Non-Association Wire (II. and III.) :—

I. Breaking Load 540 lbs. per sq. inch. % Extension on Rupture 129.
II. ,, ,, 140 ,, ,, ,, ,, ,, ,, ,, 162.
III. ,, ,, 370 ,, ,, ,, ,, ,, ,, ,, 91.

NOTE.—The Percentage Extensions on Rupture are worked out from results given in Appendix D for C.M.A. Flexible in which a 12-in. length was stretched to the breaking-point in about 2 minutes. The Extension on Samples I. to III. was measured in the same way.

In all three cases the insulation consisted of—

(1) Pure rubber.
(2) Rubber separator.
(3) Vulcanised rubber.

The thickness of these layers and their composition appear to vary in the three makes. As, however, the load is plotted in pounds per square inch, calculated from the actual loads and the initial areas of the strips, the test is on a common basis as far as dimensions are concerned. The results are shown graphically in Fig. 12, together with the results for material purporting to be of equal quality to C.M.A., but which an analysis showed to be composed of low-grade ingredients. Fig. 13 shows a set of similar curves for American " Code " wire.

Through the kind co-operation of one of the firms supplying samples, the author was furnished with a series of strips of jacket and separator compound containing definite percentages of rubber and

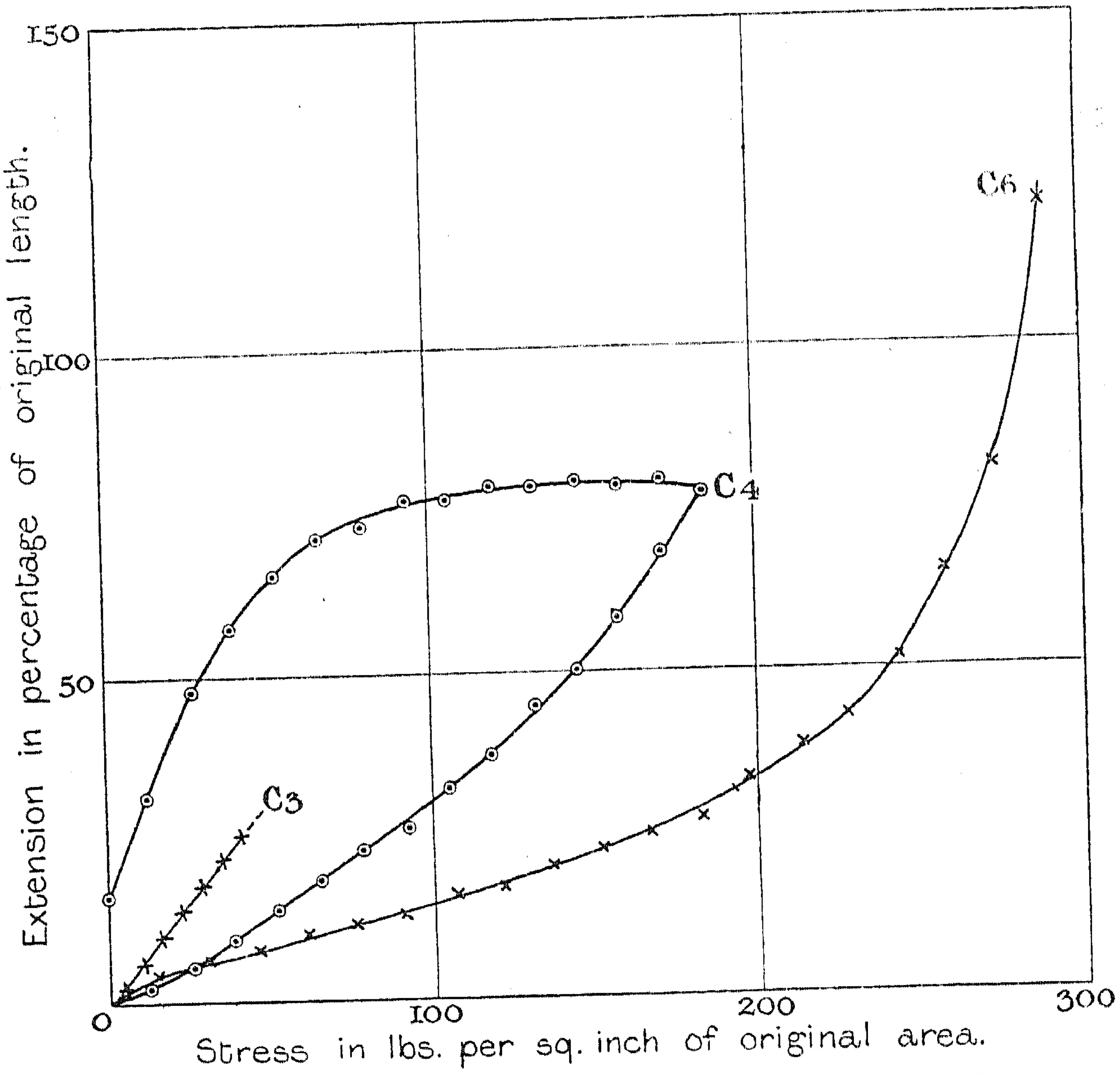


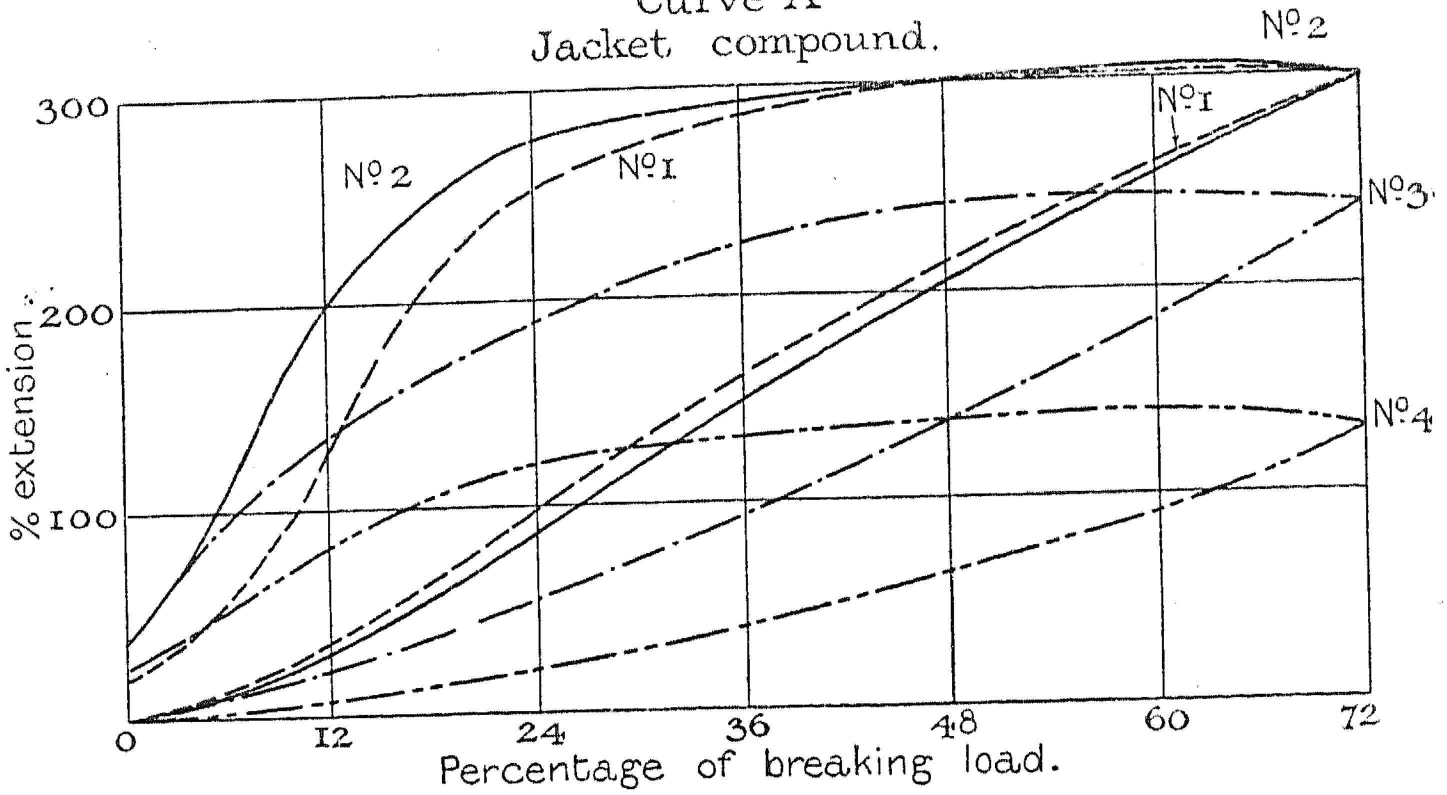
FIG. 13—Hysteresis Loops of American " Code " Wire.

C_3, Old Code Length. Broke at 48 lbs. per sq. inch.
C_4, New Code (insulation in form of tube 1 in. long).
C_6, Old Code (insulation in form of tube 1 in. long). Broke at 304 lbs. per sq. inch.

vulcanised in the same way. The other ingredients of the compound were varied according to the experience of the manufacturer, in order to produce the best results for each per cent. of rubber.

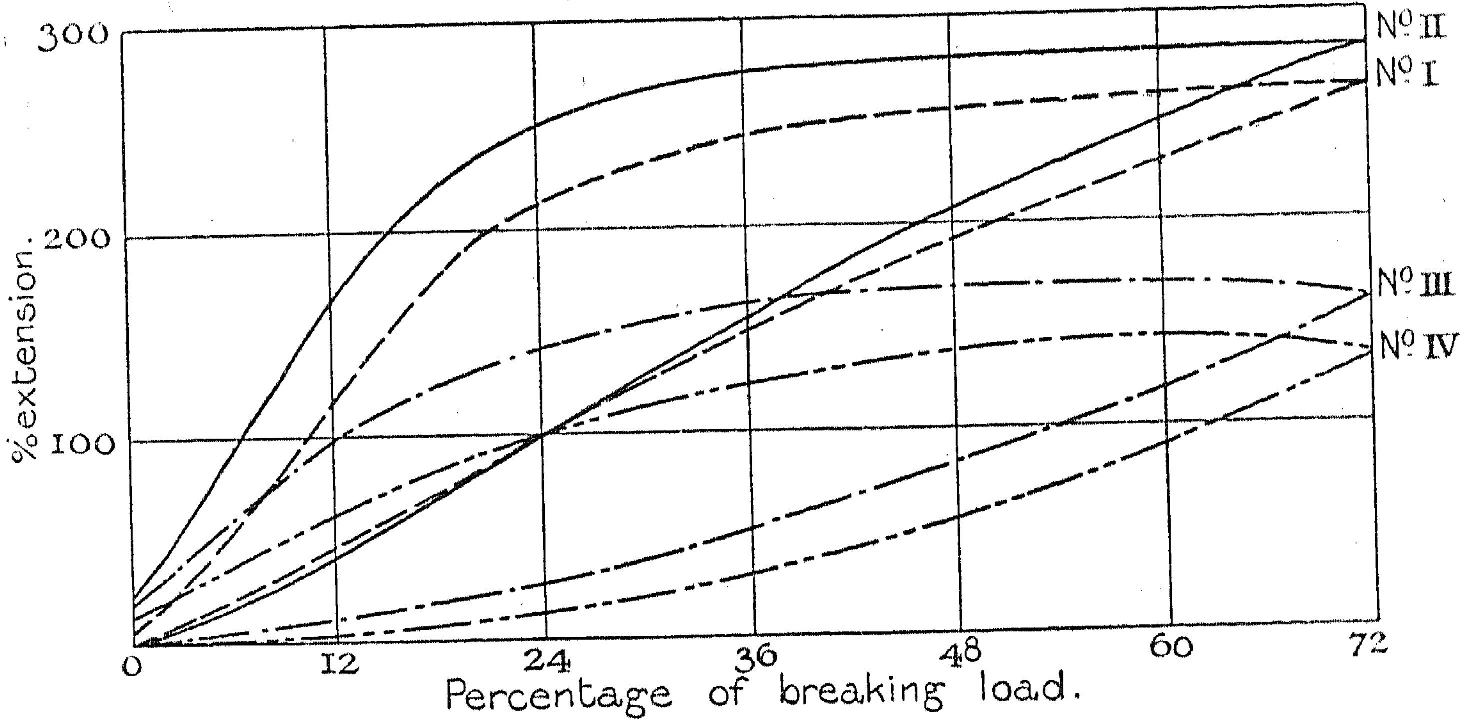
These samples were tested by the hysteresis method and the results given in Fig. 14, curves A and B are plotted on a base of per cent. of breaking load, each sample being stressed up to 70 per cent. of its breaking load. The loops plotted in this way do not place these samples in the order of their rubber contents ; a reference to the tables beneath, however, shows that C/D the coefficient of extension and F/D the coefficient of retraction place the samples in the proper order. Curves C and D, Fig. 15, show the retraction and extension curves respectively for the jacket compound plotted on a base of actual load,

Curve A
Jacket compound.



A	B	C	D	E	$\frac{C}{D}$	F	$\frac{F}{D}$
1	60	304	442	632	0·68	290	0·65
2	53	303	678	967	0·44	270	0·40
3	40	248	613	876	0·40	220	0·35
4	35	144	406	580	0·35	120	0·29

Curve B
Separator compound.



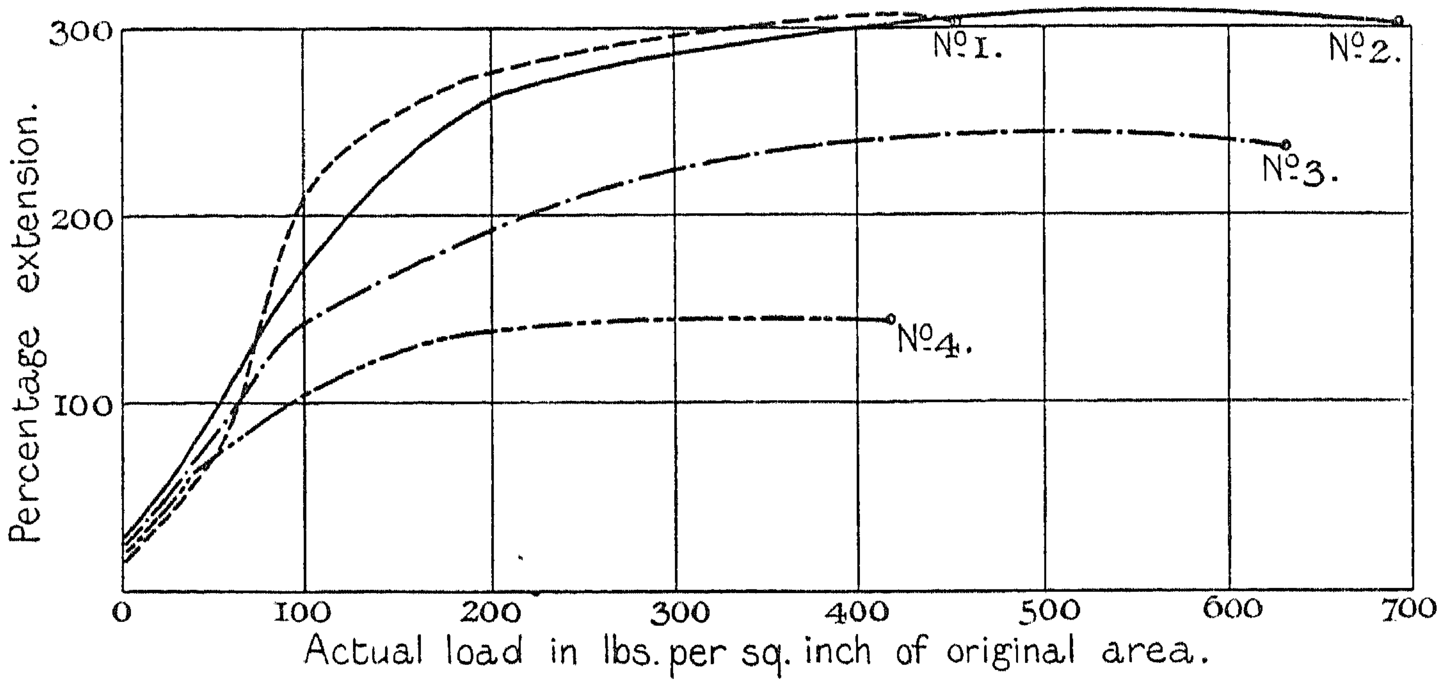
A	B	C	D	E	$\frac{C}{D}$	F	$\frac{F}{D}$
I	55	246	406	580	0·65	260	0·64
II	48	292	721	1,030	0·40	264	0·38
III	40	183	514	735	0·35	150	0·29
IV	35	123	542	775	0·22	108	0·19

FIG. 14.

Considering curve D, Fig. 15, and assuming the dotted curve No. 1 as representing the standard, there is no difficulty in placing the other samples in their order of merit.

Curve E, Fig. 16, shows the decrease in the extension of rupture after heating at 150° F. for ten days. This again places the samples in the order of their rubber contents, but the breaking-load curve F under similar conditions does not do so.

Retraction curve C obtained from curve A.



Extension curve D obtained from curve A.

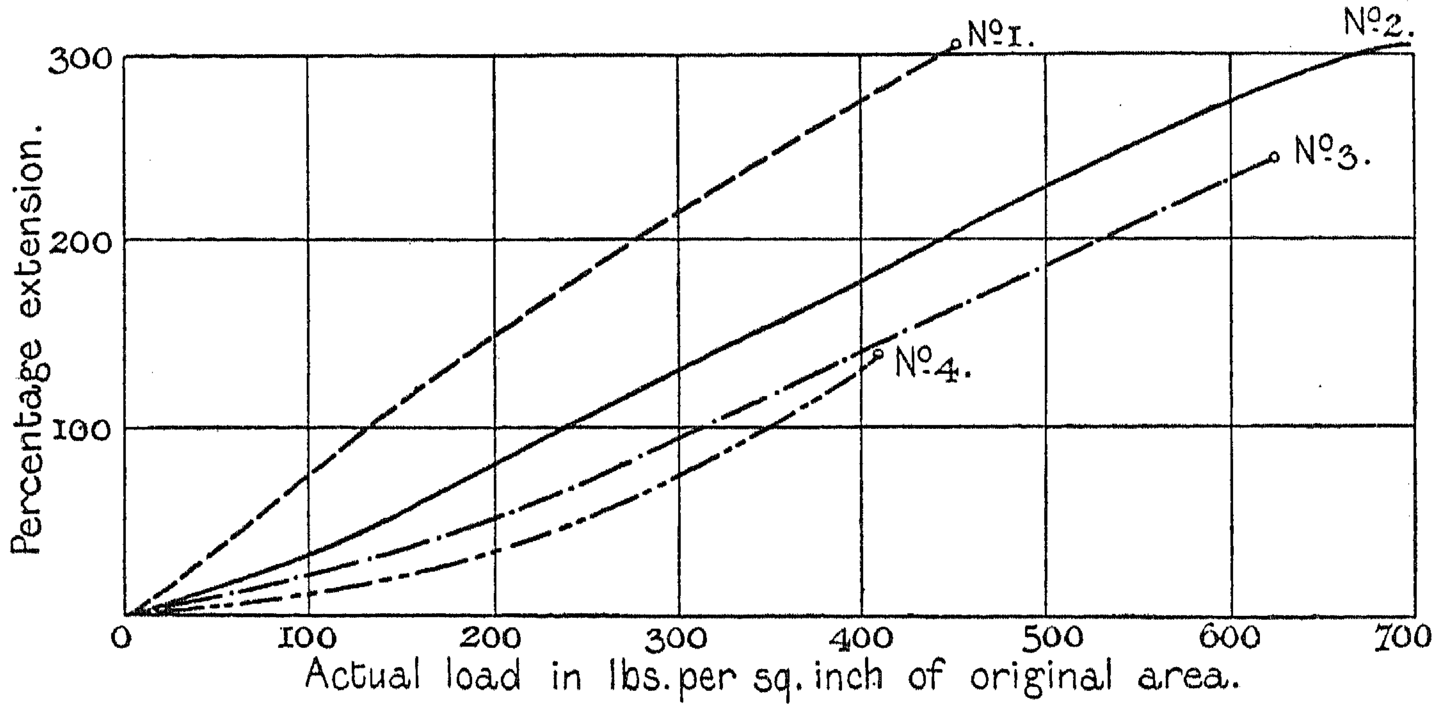
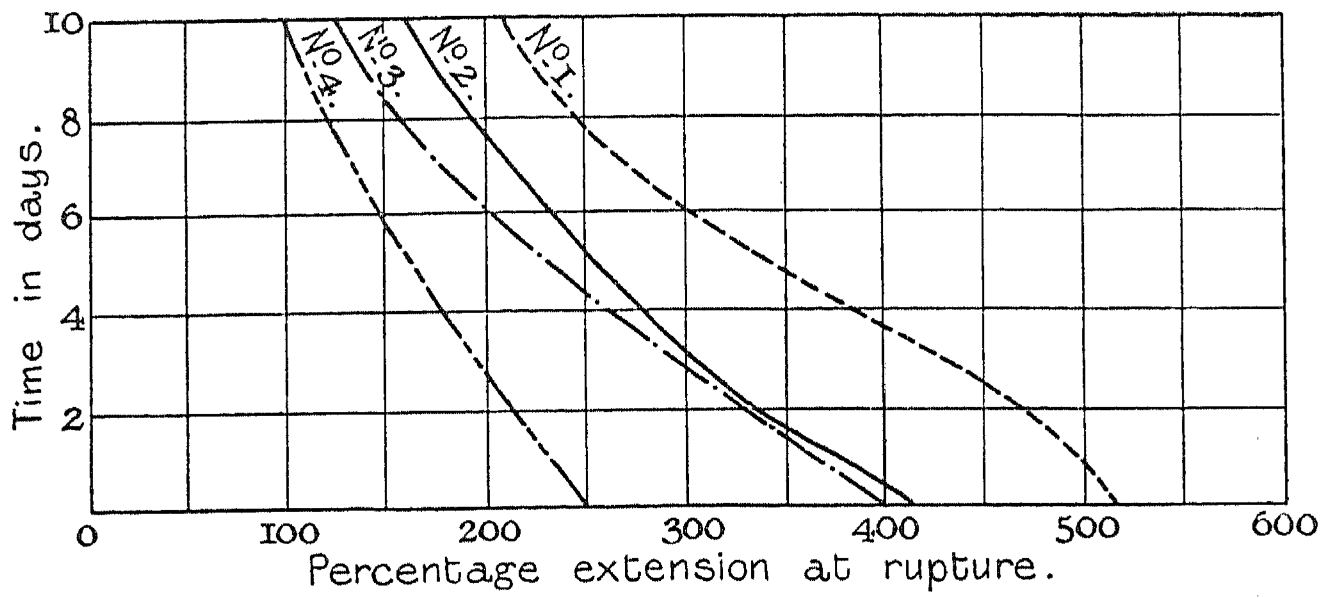


FIG. 15.

The author recognises that a great deal more work will have to be done on the stretching of rubber before the significance of these tests and their limitations are fully understood, but he suggests that by arrangement with the Cable Makers' Association a standard hysteresis loop might be arrived at for given grades of insulation. Such standard loops would to a very considerable extent serve as vulcanisation standards, and would secure the necessary physical properties of the material which give an indication of its durability, while they would further undoubtedly conduce to uniformity of manufacture. The apparatus required is simple and inexpensive, and the test is quite easy to carry out.

With regard to the relative merits of the hysteresis method, and the measurement of the permanent set on a sample that has been stretched a given length for a certain number of hours, the hysteresis test is certainly more trouble to carry out, but the results are available in a much shorter time, and further, all the conditions of the test may be easily defined, whereas with the elongation test a good deal depends upon the rate at which the rubber is initially stretched as to its subsequent behaviour. Much more information is obtainable from the hysteresis test than from the other; for instance, the amount of extension under small loads and large loads, which gives a good indication as to the state of vulcanisation of the sample, the amount of recovery as the load is removed, and at the end of the test the amount of permanent set can be measured as in the elongation test.


Extension curve E

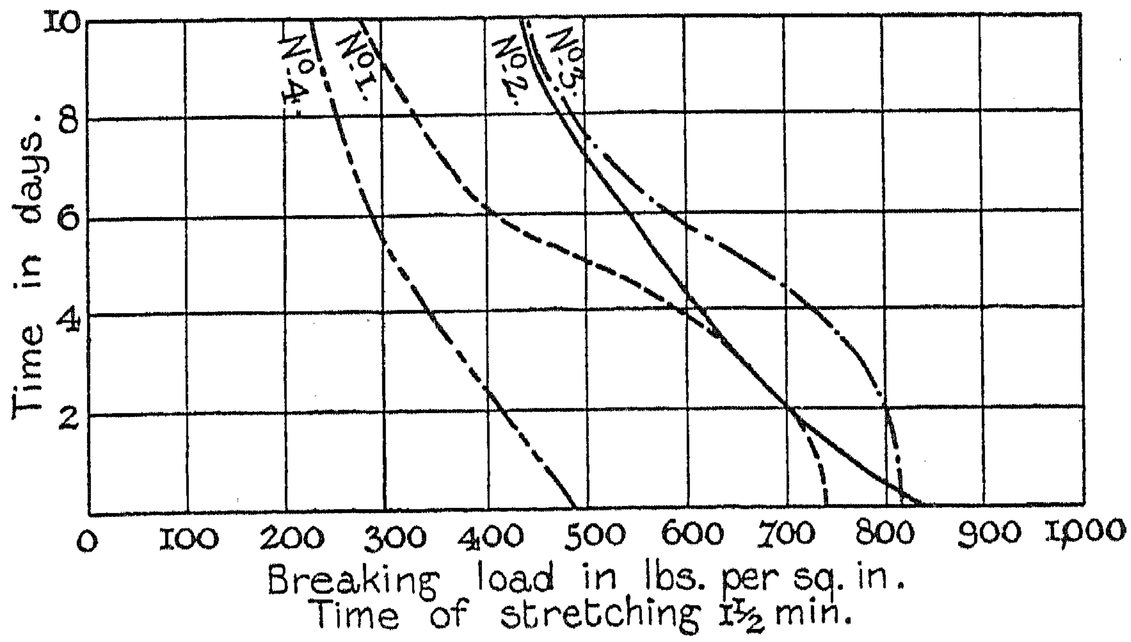

Breaking load curve F

FIG. 16.

VIII. THE STRETCHING OF RUBBER.

Apart from the hysteresis test, the stretching of rubber in the author's view forms one of the best guides as to its quality at the outset, and also affords an indication as to its probable lasting qualities.

It is curious that with the single exception of the test for Para rubber tape in the French Regulations (see Appendix B. 2), the stretching test is omitted from the official regulations, not only in this country, but also in Germany and the United States. Various forms of the stretching test are discussed under the head of Testing of Insulation (see page 75), but the author desires to give here a series of results to justify the claim that the stretching test will discriminate between

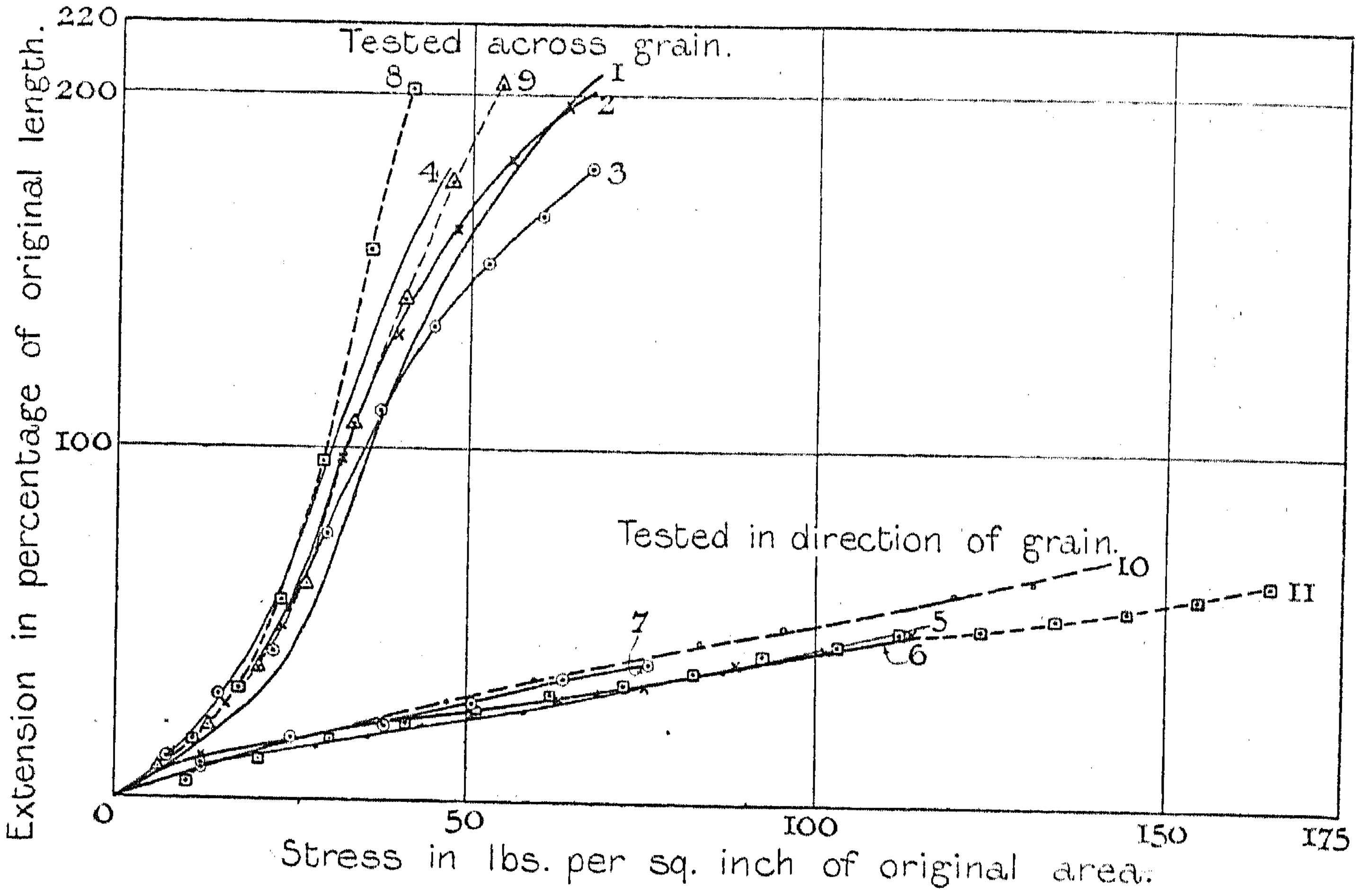


FIG. 17.—Effect of Dimensions of Test Piece. "*Cut*" Rubber Strip, Length 2 ins.

	Thickness in Inches.	Width in Inches.	Breaking Stress in Lbs. per sq. in. of Original Area.	
1	0·03	0·22	76	Tested across Grain.
2	,,	0·42	71·5	
3	,,	0·89	75	
4	,,	1·29	54·4	
5	,,	0·23	130·5	Tested in direction of Grain.
6	,,	0·53	126	
7	,,	1·05	89	
8	0·018	0·19	46·8	Tested across Grain
9	,,	0·41	60·8	
10	,,	0·28	154	Tested in direction of Grain.
11	,,	0·54	175·1	

Curves for all specimens of 0·03 in. thickness shown in full lines and for 0·018 in. thickness in dotted lines.

good and bad rubber, though not so fully as the hysteresis test will do.

The effect of varying degrees of vulcanisation on the tensile strength and elongation of Para rubber has already been discussed (see Fig. 6), and it remains to be seen what effect the various admixtures used in compounding the rubber have on these two quantities. Heinzerling and Pahl,* in a laborious and exhaustive examination, have dealt in great detail with the effect of various admixtures on the chemical and physical properties of rubber.

Table XII. gives extracts from the results they obtained with specially prepared samples containing 10 per cent. of sulphur and vulcanised for one hour at a temperature of from 135° to 138° C.

TABLE XII. (HEINZERLING AND PAHL).

Effect of Various Admixtures on the Distensibility of Vulcanised Rubber (10 per cent. Sulphur).

Reference Number.	Para per Cent.	Admixtures.		Distensibility per sq. mm. on 100 mm. Length.
		Quantity per Cent.	Nature.	
I.	90	0	—	1,100
VII.	80	5 5	Zinc oxide Chalk	760
VIII.	50	20 20	Zinc oxide Chalk	710
XVI.	30	60	Brown substitute ...	360
XVII.	50	40	White substitute ...	600
XVIII.	30	60	,, ,, ...	455
XXXI.	60	30	Ground rubber waste	650
XXXII.	30	60	,, ,, ,,	600

The same investigators give further a number of analyses of various commercial rubber articles with their physical properties. An extract from these is given in Table XIII.

DIMENSIONS OF TEST PIECES.

Rubber when under tension flows freely, and in order to ascertain what influence the dimensions of the specimen employed had on the calculated breaking stress per square inch the following experiments were undertaken :—

---

* *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1891–1892.

(1) Variation of length ; width and thickness constant.
(2) Variation of width ; length and thickness constant.
(3) Variation of thickness ; length and width constant.

The results are shown graphically in Figs. 17 and 18.

A consideration of Fig. 17, which gives the results for "cut" strip shows very clearly the difference in tensile strength and elongation in this material when tested across the grain and with the grain. When tested across the grain, the specimens begin to fail by opening transversely at the edges, while with the grain they thin out first at the centre, where a slit develops.

In general within the limits given the disturbing effect of the dimensions is not very large except in the case of width; very wide strip should be avoided owing to the difficulty in clamping it so that the stress is evenly distributed.

TABLE XIII. (HEINZERLING AND PAHL).

Effect of Admixtures on the Physical Properties of Various Commercial Rubber Articles.

Reference Number.	Indiarubber per Cent.	Sulphur per Cent.	Admixtures.		Spec. Grav.		Distensibility per sq. mm. on 100-mm. Length.
			Quantity per Cent.	Nature.	After Manufacture.	After 2½ Years.	
1	91	9	0	—	0·990	0·999	675
2	82	8	10	Chalk	1·100	1·111	600
3	43	5	7 45	Brown substitute Zinc oxide	1·400	1·490	580
4	47	7	27 16	Chalk Zinc oxide	1·400	1·500	160
5	66	0	16 9 9	Golden sulphide Chalk Zinc oxide	1·200	1·304	235
10	36	6	4 27 27	Brown substitute Chalk Zinc oxide	1·550	1·720	550

The experiments shown in Table XIV. were carried out by the author and Mr. R. K. Keer on pure rubber "spread" tape to ascertain its rate of recovery after a given extension for definite times.

A consideration of this table shows that a reduction in the amount of sub-permanent set goes on throughout the twenty-four hours after testing; indeed, it will continue as a diminishing quantity for several days. The amount of "permanent" set increases with the time the specimen is under tension and also depends upon the rate at which the stretching takes place. A reference to the stretching tests now in use (Appendix B) shows that these facts have not been considered in drawing up these tests. There does not seem to be any gain in measuring the "permanent set" a number of hours after release.

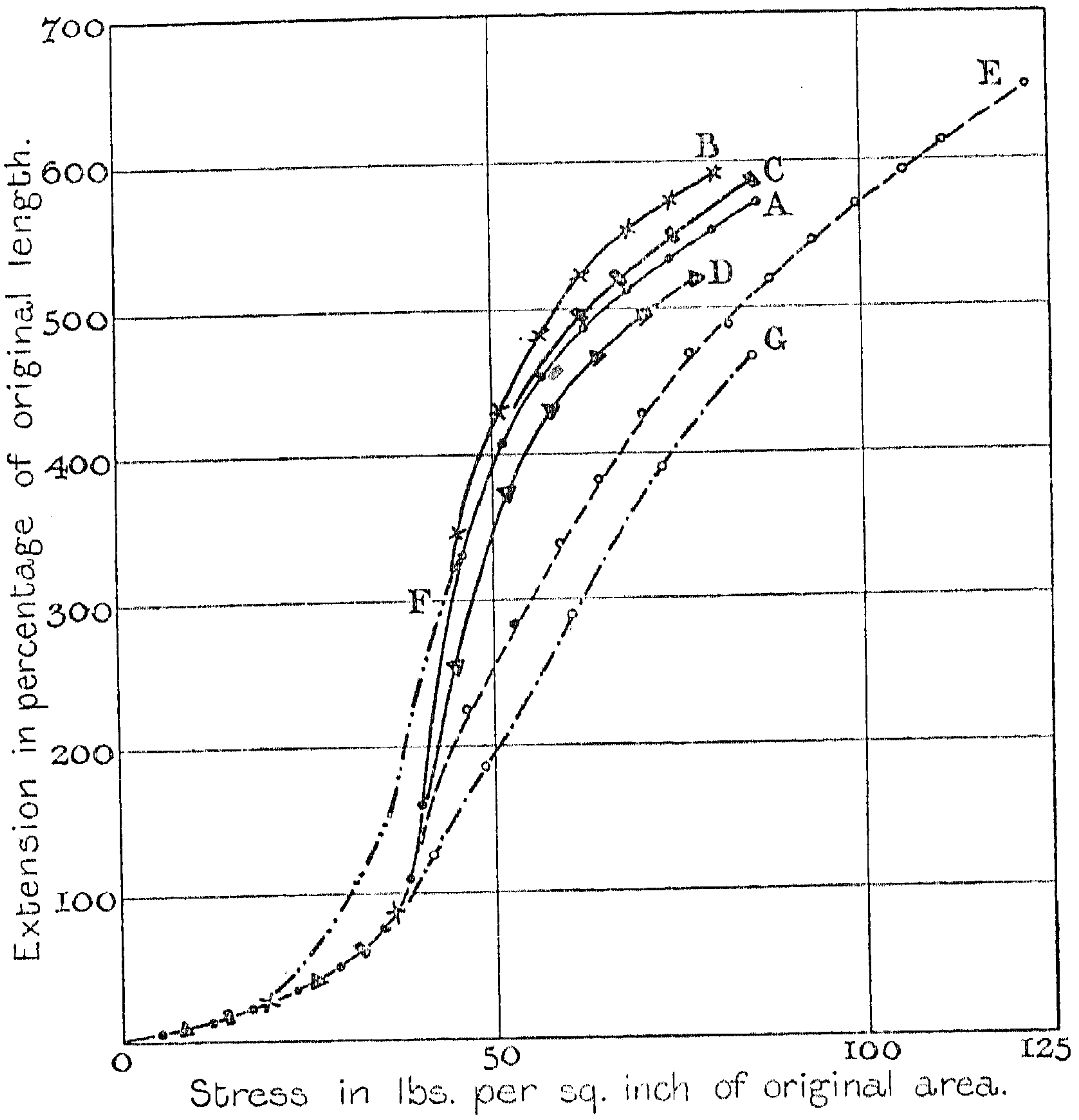


FIG. 18.—Effect of Dimensions of Test Piece. "*Spread*" Rubber Strip.

Effect of Length.

		In.		In.
A, B, C.	Width	0·71	Thickness	0·024
D.	,,	0·67	,,	0·022

		In.		Lbs. per sq. in.
A.	Length	0·5	Broke at	92·6
B.	,,	1·0	,, ,,	86·8
C.	,,	2·0	,, ,,	92·6
D.	,,	6·0	,, ,,	85·0

Effect of Width and Thickness.

Constant Length, 2 Ins.

		In.		In.		Lbs. per sq. in.
E.	Width	0·32	Thickness	0·011	Broke at	130
F.	,,	0·51	,,	0·015	,, ,,	62·5
G.	,,	0·77	,,	0·011	,, ,,	98·4

TABLE XIV.

Recovery of Rubber after Stretching.

Pure spread tape ; initial length 2 ins., width $\frac{3}{4}$ in., thickness 25 mils.

Experiment Number.	Percentage Extension on Original Length.	Time of Stretching.	Time during which Specimen was left Stretched.	Length in Inches at Release.	Length in Inches at the following Periods after Release:—			
					1 min.	1 hour.	6 hours.	24 hours.
1	100	3 secs.	Released at once	2·20	2·07	2·02	2·01	2·00
2	200	,,	,, ,, ...	2·30	2·16	2·09	2·06	2·05
3	100	,,	1 hour	2·60	2·43	2·41	2·24	2·17
4	200	,,	,, ...	4·10	3·79	3·03	2·65	2·55
5	100	,,	24 hours	3·70	3·58	3·12	2·81	2·57
6	200	,,	,, ...	4·87	4·65	4·08	3·65	3·29
7	100	½ in. every 2 mins.	Released when stretched to limit 8 mins.	2·56	2·36	2·11	2·06	2·03
8	200	,, ,,	,, ,, ,, 16 mins.	3·38	2·98	2·45	2·29	2·22
9	100	,, ,,	8 mins. for stretching + 1 hour ...	3·10	2·90	2·41	2·22	2·13
10	200	,, ,,	16 ,, ,, ,, ...	Broke	after stretching	for $\frac{3}{4}$ hour.		
10	200	,, ,,	16 ,, ,, ,, ...	4·12	3·86	3·06	2·71	2·51
11	100	,, ,,	8 ,, ,, + 6 hours ...	3·31	3·15	2·70	2·45*	2·26
12	200	,, ,,	16 ,, ,, ,, ...	4·50	4·25	3·54	3·19†	2·68

* In this case time was only 5¼ hours.

† In this case time was only 5 hours.

IX. TESTS ON COMPLETED FLEXIBLES.

In the spring of last year, at the instance and for the information of the Wiring Rules Committee of this Institution, the author carried out in the laboratories of the Municipal School of Technology, Manchester, the following series of tests on complete flexibles:—

(1) Tensile strength.
(2) Bending on a counterweight fitting.
(3) Dielectric strength I.E.E. Rules.

The following samples of twin flexibles were submitted for tests:—

Test Piece Reference Number.	Size.	Description of Insulation.	Firm.
1	35/40	Thin V.I.R.	A
2	35/40	I.E.E.	A
3	35/38	V.I.R.	A
4	23/36	C.M.A.	A
5	23/36	C.M.A., Class II.	B
6	35/40	Double pure rubber	B
7	35/40	Single pure rubber	B
8	35/40	Double pure rubber	C
9	35/40	V.I.R.	C
10	35/40	C.M.A., single pure rubber ...	C
*11	35/38	V.I.R.	B
*12	35/38	V.I.R.	D

I.E.E. = to specification of the Institution of Electrical Engineers.
C.M.A = to specification of the Cable Makers' Association.
V.I.R. = vulcanised indiarubber.

(1) *Tests for Tensile Strength.*—These tests were made on a horizontal Buckton machine reading down to 10 lbs., two specimens of each sample being tested. The results are given in detail in Table XV. The test piece was short-circuited at one end and about 2 ins. at each end were tightly lapped with several layers of black tape. The taped ends were held in the jaws of the machine with an initial length of 1 ft. of flexible between them. This method of grip was found to be quite satisfactory. A small incandescent lamp was connected in series with the flexible under test to some cells with the object of showing by the extinction of the lamp when the copper conductor broke.

A consideration of Table XV. shows that the breaking force varies a good deal with different specimens of the same sectional area. This is probably due to the way in which the twin conductors are twisted together, for if one is slightly shorter than the other it will bear a larger proportion of the load. The tests show, broadly speaking, that flexibles of the sizes submitted will break with about 100 lbs. when new. This is very much in excess of any load they are likely to be called upon to bear. As might be anticipated, the copper in nearly

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* Samples five years old in use in the School of Technology, Manchester.

TABLE XV.

Mechanical Strength of Flexibles.

Test Piece Reference Number.	Size.	Breaking Load on Flexible in Lbs.	Bending Test on Counter-weight Fitting. Number of Times up and down over 1½-inch Pulley. (Up and down=1.)
1 a b	35/40	71 93	58,850
2 a b	35/40	127 138	181,470
3 a b	35/38	104 104	54,370
4 a b	23/36	104 82	70,181
5 a b	23/36	60 82	130,699
6 a b	35/40	71 93	105,262
7 a b	35/40	123 146	200,230
8 a b	35/40	82 160	117,952
9 a b	35/40	104 —	17,736
10 a b	35/40	93 194	9,560
11 a b	35/38	104 —	265,294
12 a b	35/38	116 105	340,000
Special Gymp flexible	—	—	1,500,000 (still unbroken)

every case breaks before the rubber. It breaks very cleanly right across all the strands with a considerable reduction of area, hardening, and loss of flexibility. In the case of C.M.A. flexible supplied by two different firms the rubber broke first. Where the copper breaks first and the load is removed, the rubber will contract and bring the broken ends of the wires into contact, and so give rise to arcing. This is not very likely to occur in practice, but the author finds as a result of a series of tests, referred to on the next page, on repeated bending through a right angle at a lamp-holder, that the copper in this case also breaks first, and that the broken ends are almost invariably pulled together again by the contraction of the rubber when the weight of the fitting is taken off the cord. The average percentage elongation before rupture on a 12-in. length was 25 per cent. Test pieces Nos. 11 and 12 were cut from flexible that had been in use in the School of Technology, Manchester, for the past five years. The tests show that practically no deterioration as regards tensile strength has taken place. There was, however, a notable decrease in the percentage elongation (12 per cent.) due doubtless to the hardening of the insulation, and to the slack in the twisting being taken up by the weight of the fitting. It may

TABLE XVI.

Tensile Strength of Flexibles.—Second Series.

SINGLE FLEXIBLES.

Reference Number.	Size.	Description.	Breaking Load in Lbs.
41	61/0·006	V.I.R. Glacé	71
43	61/0·006	V.I.R. Silk	77
42	35/0·006	V.I.R. Glacé	44
44	35/0·006	V.I.R. Silk	49
46	35/40	Special thin V.I.R. Glacé	39
48	35/40	Ditto Silk	29
47	70/40	Ditto, ditto	60
45	70/40	Ditto Glacé	55
49	23/36	C.M.A. Silk	45
50	23/36	C.M.A. Glacé	42
51	40/36	C.M.A. Silk	74
52	40/36	C.M.A. Glacé	70

TENSILE STRENGTH OF BARE CONDUCTORS.

Size.	Description.	Breaking Load in Lbs.	Firm.
40/36	Tinned	68	B
40/36	"	69	A
23/36	"	38	B
23/36	"	38	A
35/40	Pure copper	23	B
70/40	" "	48	B
100/40	" "	72	A
35/0·006	" "	38	B
61/0·006	" "	67	B

possibly also be due in part to the hardening to which copper is subject if left for a long time under even moderate loads. The author felt that a dead load test would be preferable, and Tables XVI. and XVII. embody the results of a number of tests of flexibles of different grades carried out with a Salter spring balance. The flexibles were attached to lamp-holders at either end, and were knotted at the back of the cord grips, which were screwed up tightly. This form of grip proved quite satisfactory, the tension being put on by means of a screw and wheel nut.

(2) *Bending Test on a Counterweight Fitting.*—One of the severest conditions that a flexible conductor has to meet in house installation work is its use on an ordinary counterweight fitting. An apparatus was arranged to simulate as nearly as possible the bending met with under working conditions. The flexible was drawn down by an attachment to a small motor and drawn up again by the counterweight once in each revolution of the motor. The motor, which was $\frac{1}{12}$ H.P., was fed through the flexible under test and the revolutions counted until a breakage occurred in the conductor, when the motor stopped. The following are the particulars of the apparatus :—

Diameter of porcelain pulley	$1\frac{1}{2}$ ins.
Length of pull	6 ins.
Weight of counterweight	$1\frac{3}{4}$ lbs.

The results are incorporated in Table XV. (see page 70), and are certainly surprising as the extent of the endurance of flexibles under such conditions. Since the conclusion of these tests the author received from Mr. Mervyn O'Gorman a specimen of special "Gymp" flexible, the structure of which has already been referred to under the head of "Conductors" (see page 43). After running over 1,600,000 times up and down over the counterweight pulley the condition of this flexible was, as far as one could see, quite unaffected, and the attempt to break it was abandoned. The author understands that this material costs about £60 per mile, and the resistance is very high, amounting to 1·70 ohms per yard of double conductor on the specimen tested. In connection with lifts and hoists, when the ordinary flexible gives a good deal of trouble the use of "Gymp" flexible would appear to be advantageous.

Bending Tests through a Right Angle.—Flexibles in mills and factories are subjected to frequent brushing to rid them of adherent dirt, and this entails bending at the lamp-holder, also counterweight fittings are usually adjusted by grasping the lamp shade with a similar result. In order to ascertain the effect of repeated bending the author tested about sixty varieties of flexible in the following way. Five lamp-holders were mounted in a line on a wood batten with a short length of flexible depending from each, to which a 3-lb. weight was attached. The ends of the flexibles in the lamp-holder were connected in series, and a small motor ($\frac{1}{12}$ H.P.) was fed through this circuit. The motor was arranged to rock the lamp-holders through a right angle about the ends of the cord grips as centre once each revolution. When a conductor broke the motor stopped, and the reading was taken on the revolution counter attached to the motor. The flexibles were carefully inserted and treated as far as possible in the same way, and a selection from the results are given in Table XVII.

TABLE XVII.

Bending Test through a Right Angle at a Lamp-holder.

Test Piece Reference Number.	Size of Conductors.	Average Breaking Load, in Lbs.	Number of Right Angle Bends under Tension of 3 Lbs.	Description of Insulation and Finish.
101	61/·006=1/18	135	1,680	V.I.R. Glacé twin twisted
128	61/·006	—	86,810	V.I.R. Workshop
132	61/·006	—	8,250	V.I.R. Glacé circular twin
102	35/·006=1/20	93	780	V.I.R. Glacé twin twisted
112	35/·006	101	3,680	V.I.R. Silk twin twisted
131	35/·006	—	7,050	V.I.R. circular twin
104	35/40	68	9,880	Special thin V.I.R. silk twin twisted
126	35/40	127	91,860	Special thin workshop
137	35/40	97	2,470	Special thin silk circular twin
108	23/36	86	2,500	C.M.A. silk twin twisted
118	23/36	—	870	C.M.A. Glacé
124	23/36	—	4,910	C.M.A. Glacé
107	40/36	134	5,010	C.M.A. Glacé
116	40/36	—	6,880	C.M.A. Glacé
130	40/36	—	154,990	C.M.A. Workshop
150	40/36	—	2,490	C.M.A. Silk twin twisted
103	70/40	121	3,600	Special thin V.I.R. silk twin twisted
125	70/40	—	26,140	Special thin V.I.R. workshop
135	70/40	—	1,690	Special thin V.I.R. circular
154	36/38	—	2,310	Twin circular silk, 2,000 megohms
155	36/38	—	2,110	Twin circular Glacé, 200 megohms
156	64/38	—	44,580	Twin twisted silk, 200 megohms
157	64/38	—	3,190	Twin twisted Glacé, 200 megohms

It will be noticed that considerable differences exist in the behaviour of different conductors of the same sectional area and gauge of wire. This may, of course, be due in part to differences of manufacture or material, but the author is inclined to attribute it to the position of the flexible where it entered the cord-grip and where the bending took place. The two conductors may have the axis of their cross-sections at right angles to the axis of bending, or parallel to it, or in any positions intermediate to these. In practice any of these positions may be dealt with, and the figures given may therefore be taken as an indication as to what might occur in actual work.

(3) *Dielectric Strength.*—The samples were first subjected to the insulation test as set out in the 1903 edition of the Wiring Rules. The conditions of this test are well known and need not be referred to here. In the tests, the details of which are embodied in Table XVIIA, the flexibles were suspended from supports 3 ft. apart, and were at their centres about 4 ins. from a pan of boiling water 14 ins. in diameter. All the samples submitted successfully withstood the I.E.E. test, and were afterwards tested with a gradually increasing alternating current voltage until they broke down.

TABLE XVIIA.

Dielectric Strength of Flexibles.

Test Piece Reference Number.	Thickness of Rubber in Mils.	Breakdown Pressure, in Volts.	Nature of Insulation from Observations.
1	16	8,000	Cotton over conductor V.I.R. only
2	17	21,500	Pure rubber, two layers laid opposite ways
3	27	24,200	V.I.R. separator and pure rubber with longitudinal joints
4	34	23,300	V.I.R. separator and pure rubber. Poor and overcured. No cotton next conductor
5	35	26,000	V.I.R. separator and pure rubber of good quality. No cotton next conductor
6	19	21,000	Pure rubber, two layers
7	8	5,100	Cotton braid, cotton yarn, single layer pure rubber. Cotton next conductor
8	24	25,000	Cotton braid, double layer pure rubber. Cotton next conductor
9	34	22,000	V.I.R. separator and pure rubber
10	—	3,200	Cotton braid, single layer pure rubber. Cotton next conductor
11	24	20,000	V.I.R. and separator. Cotton next conductor. Double braided. Five years old

X. TESTING OF INSULATION.

The insulation of flexibles, while following in general the usual lines adopted for rubber cables, is subject to a rather different set of effects, in that the conductors of opposite polarity are in close contact throughout their length, and that the ratio of the amount of surface exposed to the air by the insulation to its thickness is larger in the case of most flexibles than for cables, and the maximum thickness of insulation to be dealt with is small.

Considering the features which it is desirable that the insulation should possess, and placing them in the order of their relative importance, we have :—

(1) Durability.
(2) High initial insulation resistance.
(3) Dielectric strength.

The first is undoubtedly in the case of flexibles the most difficult to obtain, and also the most difficult to test for ; while the second, although very generally considered of small importance, often affords a safer guide to the real character of the insulation than the high-voltage puncture test would do. The puncture test for dielectric strength, while usually specified for flexibles, is very rarely carried out in practice.

Table XVIII. gives the puncture voltage, insulation resistance, and electrostatic capacity of some American cables containing definite relative amounts of rubber in their insulation.

TABLE XVIII. (CLARK).*

Significance of Electrical Tests.

Relative Amount of Rubber.	Breakdown E.M.F., in Volts.	Capacity Microfarads per Mile.	Relative Percentage Deterioration in one Year in Elastic Limit.	Insulation Resistance in Megohms per Mile.
1	17,000	2	66	534
2	19,000	1·2	30	1,185
3	18,000	1·0	20	1,150

The above figures are based on twelve tests of each class. They are quoted, not to show absolute values, but to make clear the point that the cheaper grades of insulation do not retain their elasticity. A consideration of the table shows that neither the puncture test values nor the initial insulation resistance afford accurate indications of the durability of the rubber.

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* "Comments on Present Underground Cable Practice," Wallace S. Clark, *Proceedings American Institute of Electrical Engineers*, vol. 25, 1906, p. 207.

In order that the tests specified for an insulating material may have any real practical value it is essential that they should be simple in character, and easy to carry out. Viewed from this standpoint, any elaborate chemical analysis is out of the question, except in connection with large contracts; and we have to fall back upon the simpler chemical tests, such as the amount of acetone extract and the amount of ash, and the mechanical tests for tensile strength, and elongation, the physical test as to the behaviour in dry and moist heat, and the electrical tests as to dielectric strength and insulation resistance. We have by means of these tests to discriminate between insulation in which a certain minimum quantity of fine Para, Ceylon, or other good rubber has been employed and that into which recovered rubber and rubber substitutes and mineral matter too largely enter.

Pure fine Para rubber contains about 1½ per cent. of matter soluble in acetone, but during the process of vulcanisation this increases to from 3 per cent. to 4·5 per cent. Oxidised oils and rubber substitutes are soluble in acetone, so that the percentage of acetone extract above that native to good vulcanised rubber is a guide to the purity of the rubber.

In order to recognise the relation of the resinous extract obtained to the amount of indiarubber present, the percentage figures for these two constituents should always be calculated separately, so as to show the absolute percentage of resin contained in the indiarubber of the sample alone, and not in the whole contents of the compound.

Table XIX. shows the increase in resinous matter in a few typical varieties of rubber when vulcanised with 10 per cent. of sulphur.

TABLE XIX. (C. O. WEBER).*

Increase in Resinous Matter in Various Rubbers on Vulcanisation with 10 per Cent. of Sulphur.

Brand of Rubber.	Resin in Washed Rubber.	Resin in Vulcanised Rubber.
Para Fine	1·2 per cent.	4·04 per cent.
Ceara	2·1 ,,	5·12 ,,
Upper Congo	3·7 ,,	7·60 ,,
Lagos	4·5 ,,	7·13 ,,
Sierra Leone	6·1 ,,	9·97 ,,
Borneo	10·3 ,,	14·44 ,,

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* "The Chemistry of Indiarubber," London, 1902, p. 264.

The increase in the resinous extract only occurs in rubbers vulcanised by heat; cold vulcanised rubbers invariably show the normal percentages of resin. A consideration of this table considerably discounts the value of the conclusions based on the acetone extract in respect of the rubber contained in an unknown sample. On the other hand, the amount of extract may always be taken as a safe guide as to whether the sample has been manufactured from Para or not.

The following specification has recently been agreed by the American Rubber Covered Wire Engineers Association*:—

"For insulating compound containing not less than 30 per cent. by weight of fine dry Para rubber.

"The vulcanised rubber compound shall contain not more than 6 per cent. by weight of acetone extract. For this determination the acetone extraction shall be carried on for five hours in a Soxhlet extractor as improved by Dr. C. O. Weber.

"The rubber insulation shall be homogeneous in character, shall be placed concentrically about the conductor, and shall have a tensile strength of not less than 800 lbs. per square inch.

"A sample of vulcanised rubber compound not less than 4 ins. in length shall be cut from the wire with a sharp knife held tangent to the copper. Marks shall be placed on the sample 2 ins. apart. The sample shall then be stretched until the marks are 6 ins. apart and then immediately released; one minute after such release the marks shall not be over 2⅜ ins. apart. The sample shall then be stretched until the marks are 9 ins. apart before breaking. For the purpose of these tests care must be taken in cutting to obtain a proper sample, and the manufacturer shall not be responsible for results obtained from samples improperly cut."

The following elongation test is given by J. Langan† as being intended principally for national code wire, and he considers that even by omitting all conditions as to rubber it would compel results that would be entirely reliable and satisfactory for all conditions of code use.

Elongation Test (*Langan*).—The insulating material of every wire must stand an elongation test of stretching three times its length several times; that is, a piece 2 ins. long must stretch to 6 ins. and promptly return to within 20 per cent. of its original length. It must then stretch four times without break or rupture, and return to 25 per cent. of its original length.

The author has examined a number of specimens of flexibles purporting to be "new and old code wire" and has found them to be poor, hence the necessity for the addition of an elongation test to the tests specified in the national electric code, which are given in Appendix A. 2*d*. A detailed examination of "code" wires is given in Appendix D.

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* W. S. Clark, *Proceedings American Institute of Electrical Engineers*, vol. 25, No. 4, 1906, p. 203.

† J. Langan, "Rubber-covered Wires." *Ibid.*, p. 189.

Dry and Moist Heat Tests.—The following tests are generally referred to as "Admiralty tests," but must not be taken as officially representing the Admiralty specifications:—

The "dry heat" test is carried out in an air bath and consists in exposing the samples for one hour to a temperature of 270° F. The "moist heat" test is carried out in a digester at 320° F., the samples having to withstand this temperature for three hours without injury. This test is purposed to disclose the presence of rubber substitutes by their saponification. Pure rubber will not stand these tests, as it melts.

The following elongation test is attributed to the Admiralty, and is certainly the best in common use at the present time: A 14-in. specimen to be clamped for 1 in. at the ends and stretched to double its length—*i.e.* 24 ins.—to remain in this state for twenty-four hours without breaking, and on release after a further twenty-four hours the permanent elongation on the 12-in. length should not exceed 15 per cent.

The relative durability of vulcanised rubber and pure rubber flexibles in mills and other trying situations is a debateable point, and one on which the author hopes the discussion of this paper may throw further light. As things stand at present the Cable Makers' Association only make "C.M.A." flexibles in vulcanised rubber, and if engineers are to pin their faith to this material the author considers that the high-voltage tests should be made after immersion in water. (See Appendices A. 2*d*, C. 2*d*).

The immersion test could hardly be applied with advantage to pure rubber flexibles on account of the amount of water absorbed by this material.

A consideration of the existing tests detailed above shows a great lack of uniformity and an undoubted want of a reliable "durability" test. The author suggests that a comparison with a standard hysteresis loop, together with a carefully specified stretching test after heating at 150° F. for a given time in air, would give much greater certainty as to the probable durability of the material than any of the tests referred to above. The author hopes to investigate this matter further in the near future, as such a test should be applicable to the thick coatings of large cables as well as to flexibles.

XI. THICKNESS OF INSULATION.

A specified thickness of insulation has long been regarded as a desideratum, and where a material of fairly constant composition, such as fine Para rubber, is employed a specification of the thickness to be used may be of value.

Further, it may be desirable for mechanical reasons, or in connection with the oxidation on exposure to the air, to specify certain minimum limits as to thickness with various materials; but the author wishes to urge that, apart from the above, with a highly variable material like vulcanised rubber the specification of the thickness to be employed is not of much value as a guarantee of the subsequent satisfactory behaviour of the material. The minimum thicknesses specified in the regulations of various countries are as follows :—

Table XX.

Thickness of Insulation for Flexibles.

English.—Pure Rubber, I.E.E. :—

16 mils. up to 125 volts.
20 „ „ 250 „

Vulcanised Rubber, C.M.A. :—

34 mils. smallest conductor.
37 „ largest „

American (see Appendix A. 2*d*).—Vulcanised rubber :—

31 mils. minimum.

French (see Appendix B. 2*a* to *d*).—Vulcanised rubber :—

	Diameter of Core. 1 mm.	Diameter of Core. 2 mm.
(*a*) "Medium" insulation	24 mils.	28 mils.
(*b*) "High" insulation	32 „	36 „
(*c*) "Very high" insulation	40 „	40 „

For pendants the thickness may be reduced to 16 and 24 mils. for classes *a* and *b* respectively if braided with waxed silk.

German (see Appendix C, Table XXIV.).—Vulcanised rubber, smallest conductor: maximum 43 mils., minimum 31 mils.; largest conductor: maximum 55 mils., minimum 39 mils. For counterweight cord, minimum 23 mils.

The vulcanising rubber may be applied to the conductor in two ways. In the first method, which is most commonly adopted in this country, the conductor, after being lapped with pure rubber tape, is laid between two ribands of vulcanising rubber and passed between two grooved steel discs so placed that the grooves form a die of the required diameter. The discs are furnished with cutting edges which shear off the superfluous rubber and cause the freshly cut edges to unite by pressing them together. After vulcanisation the joint is considered to be as strong as the remainder of the material. The author has tested these joints by removing a short length of the conductor and blowing out the tube of insulation thus formed by means of a bicycle pump and valve, and has found that in most cases the joint yields first.

The second method consists in forcing the vulcanising compound by means of a screw worm round the conductor as it passes through a die much in the same way as the lead covering is formed round a cable. In order that the rubber may flow freely the apparatus has to be warm, and the finished insulation must be allowed to cool and harden before coiling. This method is largely used on the Continent and in the United States, and although the joint is eliminated, which may be considered an advantage, the conductors will very frequently be found to be considerably decentred.

A cotton wind over the conductors, which is absent in the case of C.M.A. flexible, seems to be desirable, as it prevents the direct contact of the pure rubber and the conductor, which is injurious if the tinning is defective. It also prevents the insulation from sticking to the wires, which it does very tenaciously, making it difficult to get out all the wires for connecting purposes, and it further keeps these wires clean and free from rubber.

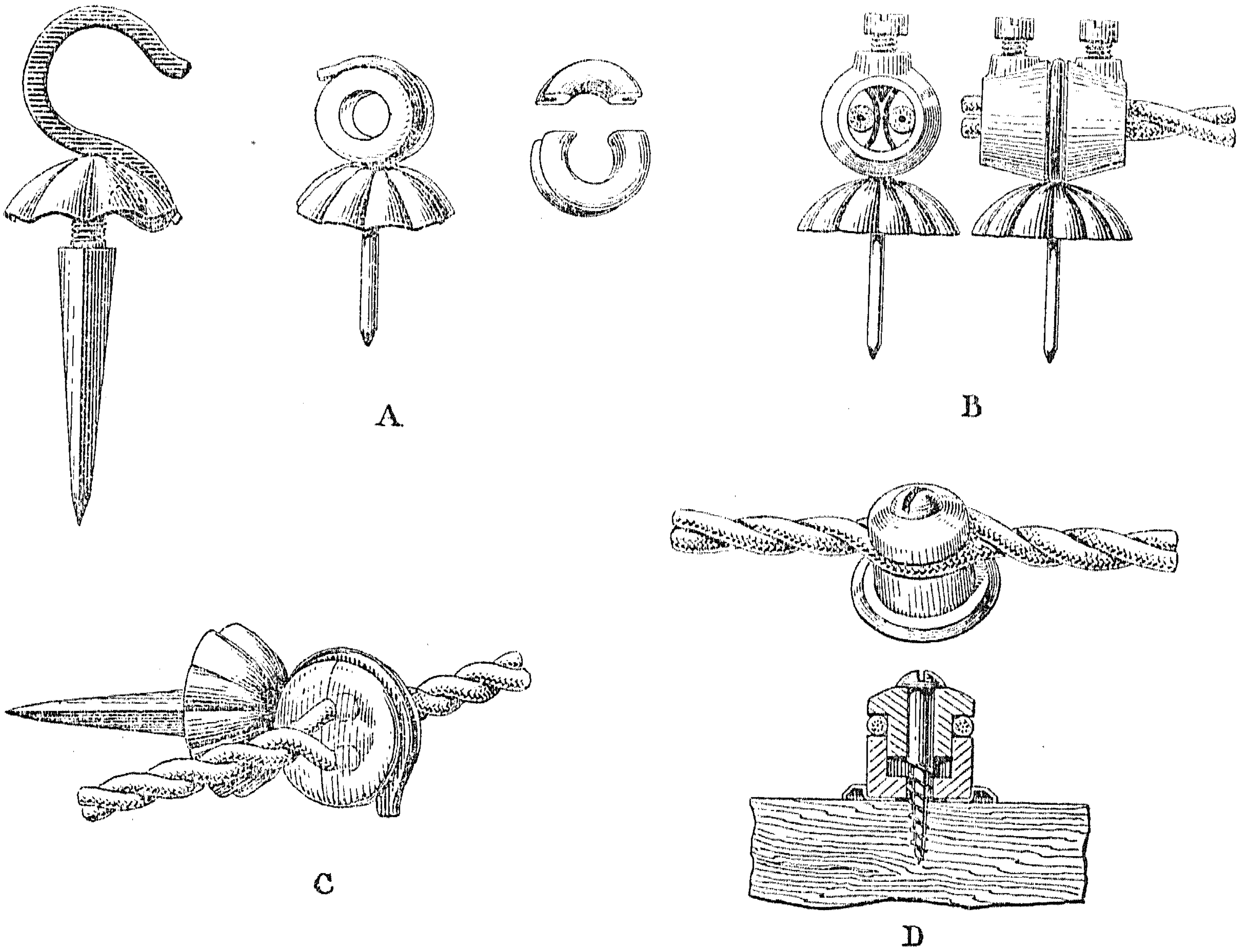

FIG. 19.

XII. FLEXIBLE WIRING SYSTEMS.

These systems, in which flexibles supported on insulators are employed, are used to a considerable extent on the Continent, on account of the cheapness and ease with which they may be installed.

The best known and most widely used of these systems is that of Peschel; it was introduced in Germany in 1893 as being cheaper than wood casing and having a less fire risk.

Originally the so-called ring insulators were employed on this system, the conductors hanging from them in a series of loops, but they are now only occasionally used. They consist of grooved rings of porcelain or coloured glass, either in one piece or split, the latter being used in order to put in extra support to a wire which has already been run or for heavy cable. These rings are sprung into small spring hooks furnished with either pins, nails, screws, or eyes, as shown at A in Fig. 19.

To strain up the flexibles at intervals special clamp insulators are required. They consist of a short porcelain tube, in which the flexible is held fast by two screws forced down between two fibre strips, causing these to wedge the cord against the tube as B in Fig. 19.

Another form of grip insulator shown at C, Fig. 19, consists of a split insulator with two or three ribbed channels in which the cords are more or less tightly held when the insulator is clamped by the spring hook. The installation of the unsplit rings is inconvenient and unsatisfactory, in that the flexibles are frequently slack, and the wire is damaged when the rooms are cleaned, and further the supporting of the hooks by pins or nails is not very sound except when used on woodwork.

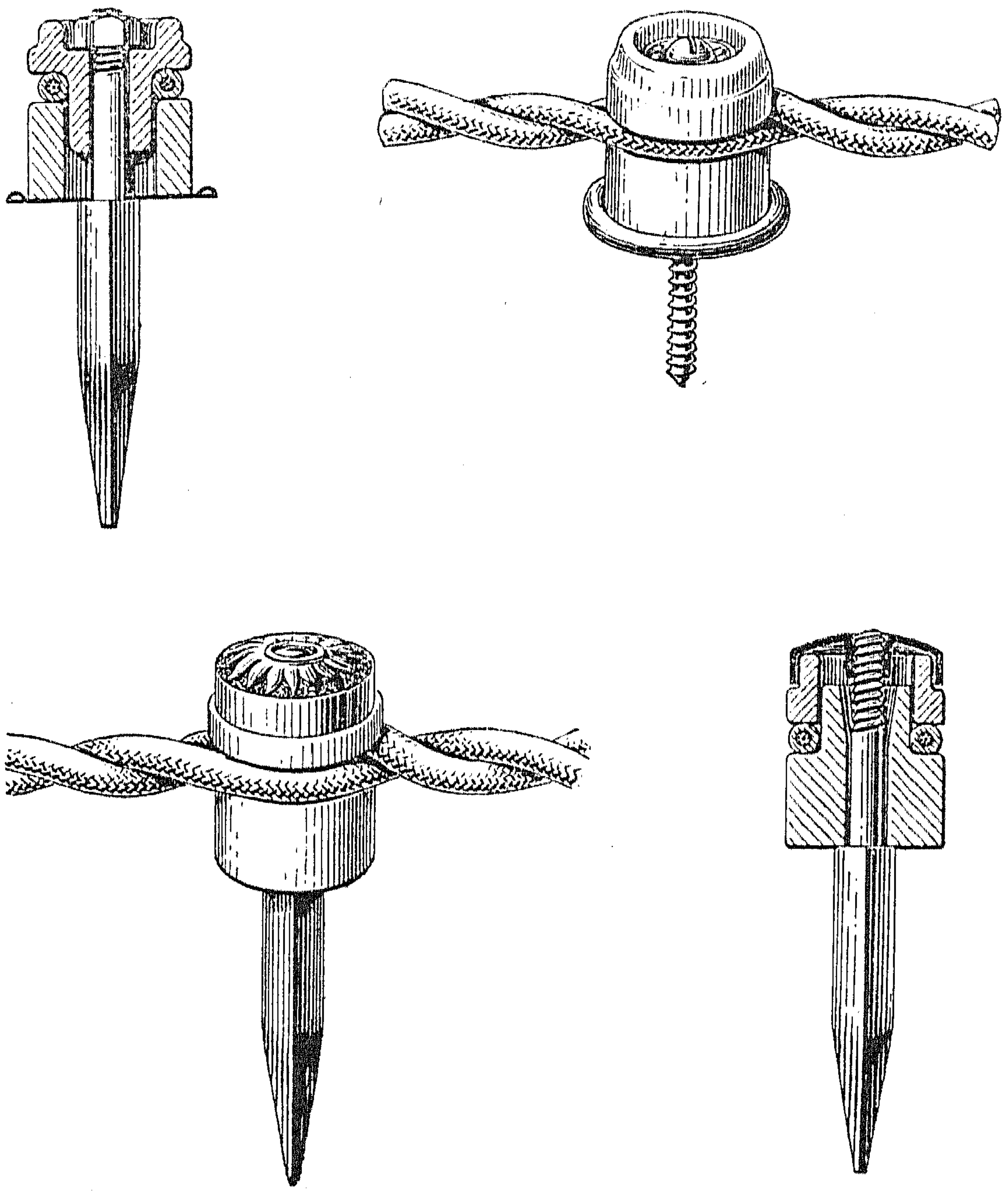

FIG. 20.

A very much better job is made by employing the type of insulator shown at D in Fig. 19, where on screwing up the fixing screw, one part of the insulator telescopes into the other, gripping the cord between the edges.

In the School of Technology, Manchester, a room has been wired as an example of this system, and has given no trouble during the six years it has been installed.

The flexibles, however, when fixed on the Peschel system, are only about half an inch from the walls, and in order to give sufficient space to allow of the walls being distempered without removing the wiring these insulators in Manchester have been mounted on paterases. The flexibles on the Peschel system may, if desired, be taken down and replaced when the redecoration is completed.

An improved form of insulator ("Reformrolle") has been placed on the market by Hartmann and Braun which possesses the considerable advantage that the pressure exerted on the flexible is quite independent of that required for the fixing of the insulator. The various forms are shown in Fig. 20.

The clamp insulators with flexibles are very popular in Germany, one firm alone supplying many millions annually. They are also largely used in France, Italy, Belgium, and Switzerland. There is a tendency now to run the wires in metal tubes, to secure additional mechanical protection where the lowest prime cost is not an absolute essential.

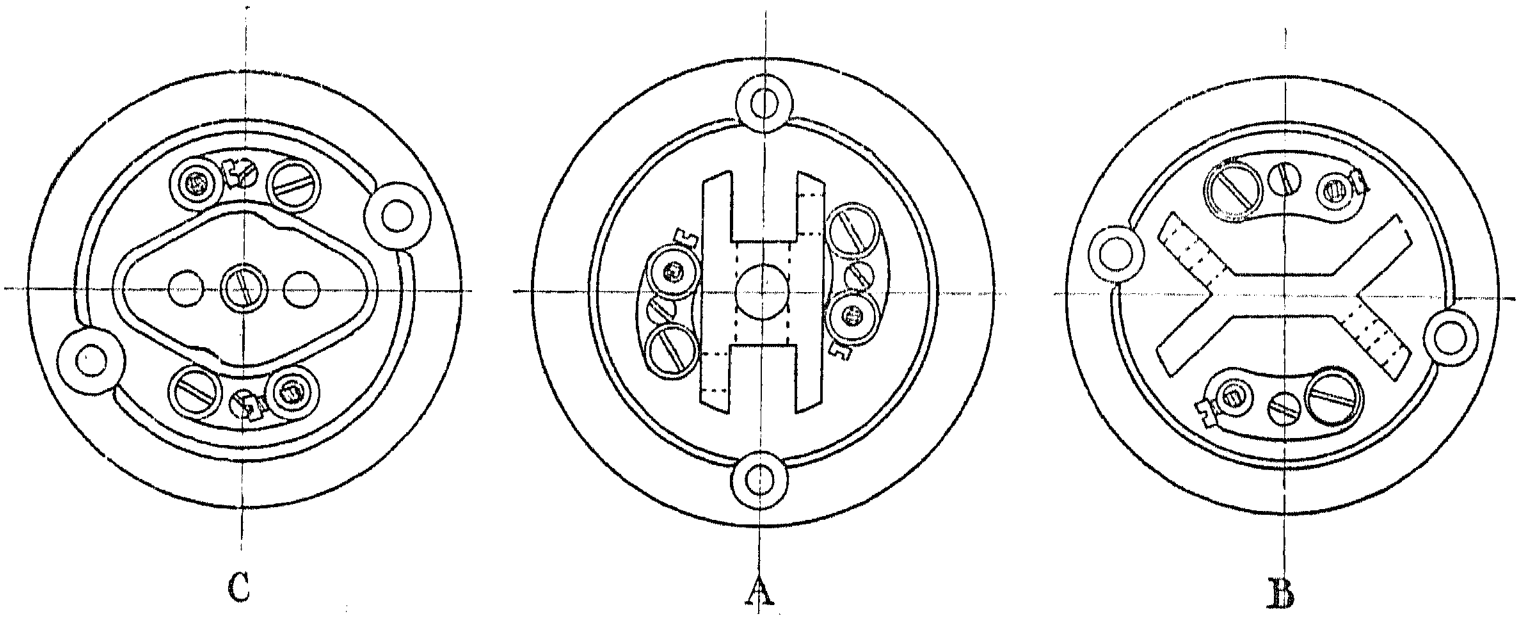

FIG. 21.

In Germany cotton-covered flexible costs from 2d. to 4½d. per metre and silk-covered from 4d. to 7d. The prices of the insulators vary from 6d. per 100 for white glazed porcelain to 4s. 10d. for the "Reformrolle," which are intended for well-decorated rooms. It is claimed that flexible wiring can be installed without making a mess or injuring decorations, and in Germany the cost per point exclusive of the lamp-holder, etc., varies from 10s. to 18s.

XIII. ATTACHMENTS FOR FLEXIBLES.

The attachment to the ceiling rose is, generally speaking, satisfactory in the best forms now on the market. With a view to determine the loads which ceiling roses will support without putting any strain upon the terminals, the three types shown in Fig. 21 were selected, and flexibles carefully inserted, the ends being, however, left quite free. The load was applied gradually and its value noted when slipping commenced. The average loads for slipping are as follows :—

Type (See Fig. 21).	Load in Lbs.
A	40
B	27
C	45

In some cases it was found that while the insulated covering maintained its position, the conductors were pulled through owing to the extensibility of the covering being considerably greater than that of the conductor. The hole in the cover of the ceiling rose is in many cases too small to admit C.M.A. flexible, which is much to be regretted, as it certainly limits the present use of this excellent material.

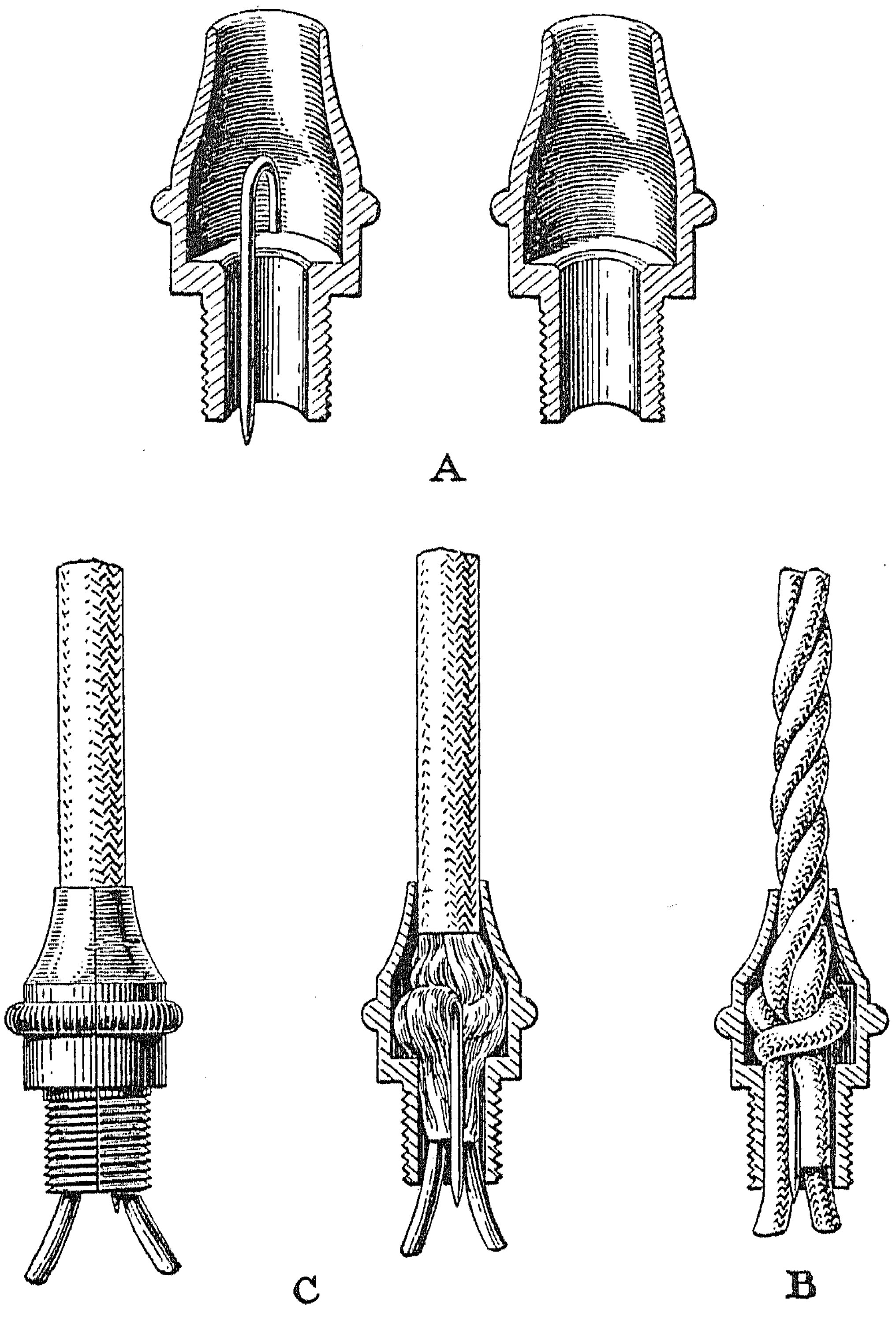

FIG. 22.

With regard to lamp-holders, with twin-twisted flexible the use of the ordinary single-hole cord-grip should be prohibited, and the older form with two slots should be reverted to, so that the conductors may be clamped when separated, and not forced tightly together. In general, the cord-grip arrangement is too cramped in design, and a good deal of improvement might be effected without sacrificing the appearance of the fitting.

The cord-grips are commonly made in one piece with a central hole; the wireman has to split the grip down the centre, and enlarge the two half-round channels thus formed to the desired size. The remains of the grip after this operation has been performed are usually of the most slender description.

With circular flexibles the single-hole cord-grip cannot very well be avoided, but in this case the filling that is put in to make up to the circular form helps largely in preventing injury to the insulation of the conductors through their being forced together.

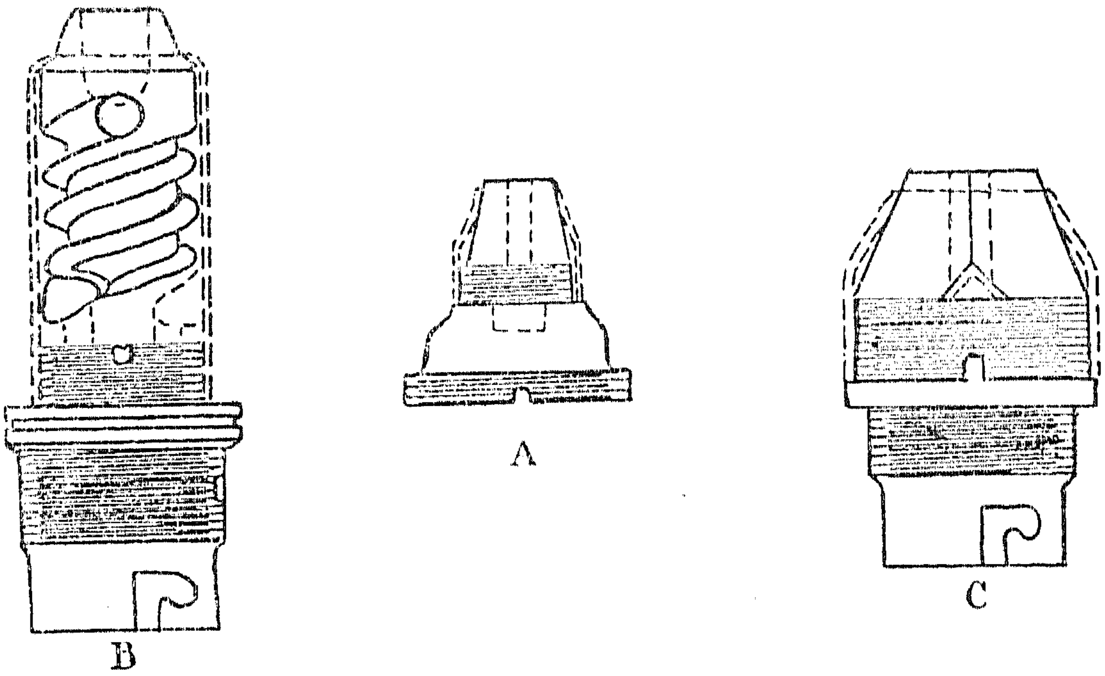

FIG. 23.

The braiding possesses considerable mechanical strength, and this should be taken down into the grip, the ends being whipped or just touched with a trace of Chatterton to prevent fraying.

An interesting series of cord-grip arrangements has been recently put on the Continental market by Messrs. Hartmann and Braun. The various devices are shown in detail in Fig. 22. It must be borne in mind in connection with these fittings that the regulations of the Verband Deutscher Elektrotechniker call for the inclusion of a suspending cord other than the conductors for counterweight flexibles (see Appendix C 2*d*). The nipple which screws into the top of the lamp-holder is made in halves; one half is furnished with a hook, Fig. 22 A, which is passed through a knot in the suspending cord, as at B. With flexibles in which the suspending cord is of stout cotton the hook shown may be placed behind the knot, as at C in Fig. 22.

Some types of cord-grip on the English market are shown in Fig. 23. The average loads at which slipping took place are given in Table XXI.

TABLE XXI.

Fig. 23.	ENGLISH CORD-GRIPS.		Average Load in Lbs. at which Slipping took place.
	Description of Grip.	Type of Flexible.	
A	Boxwood, single-hole...	Twin twisted	20·5
B	Scholes' porcelain spiral	”	28·0
C	Boxwood, single-hole...	”	18·0
	"Thikflex" holder ...	Workshop ...	46·0
D	Boxwood, with two grooves from old lamp-holder ...	Twin twisted	53·0

A further set of attachments by Hartmann and Braun[*] are shown in Fig. 24.

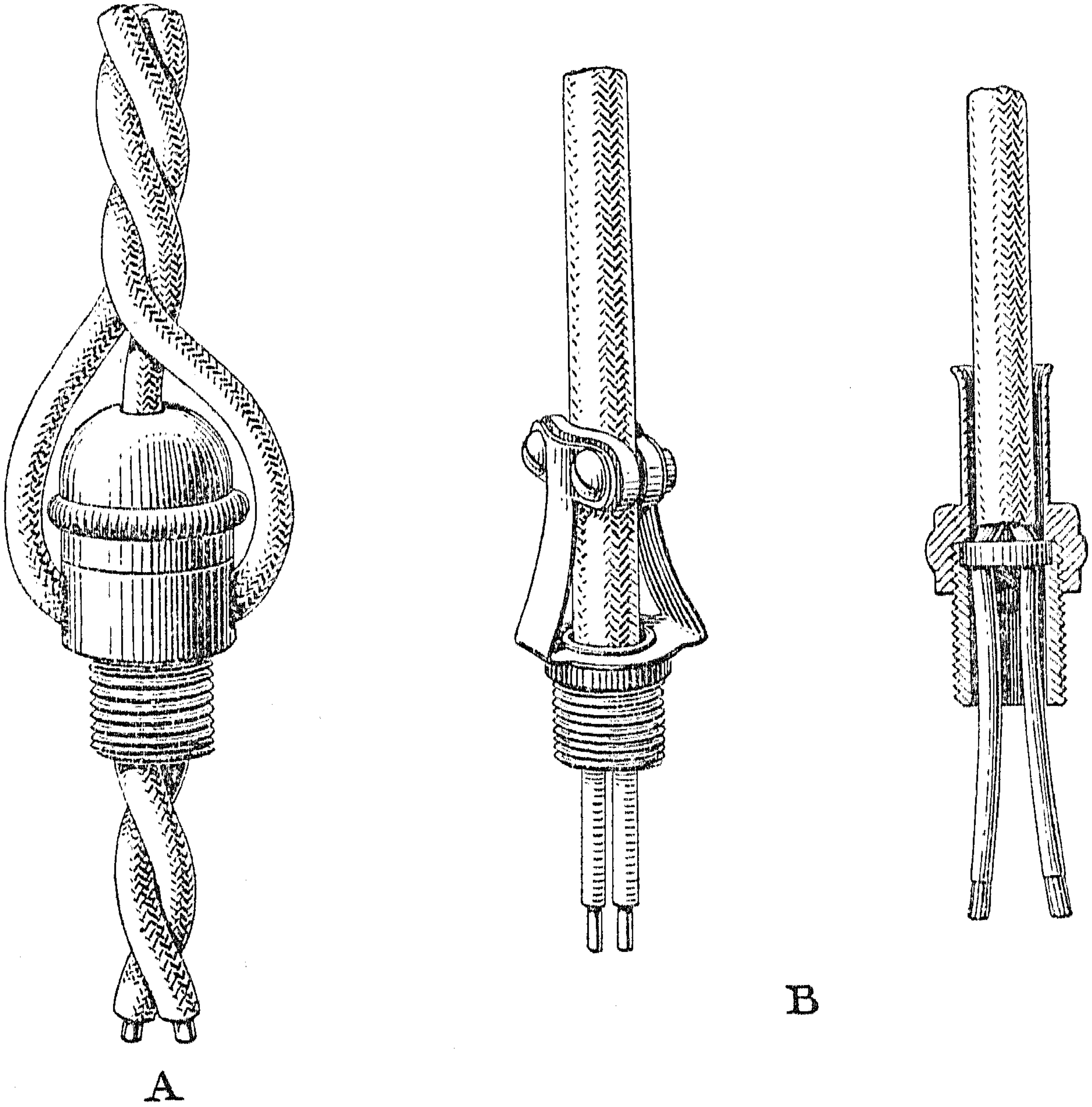

FIG. 24.

In Type A the suspending cord is carried into the screw cap and knotted, the conductors entering the nipple at the sides; in Type B the suspending cord passes through a hole in the centre of a hard fibre disc and is then knotted while the conductors pass through separate holes at the sides of the disc. Both these types possess the advantage that when in use the flexibles cannot be sharply bent at the lamp-holder.

The weight of fittings commonly supported by flexibles is given in Table XXII.

TABLE XXII.

Weight of Fittings commonly used on 35/40 *and* 70/40.

	Lbs.	Ozs
Single light pendant, tulip shade, lamp, and holder	0	14
Opal shade 8 ins. × 4 ins. deep	0	15
Enamelled iron shade 10 ins. × $3\frac{1}{4}$ ins. deep	0	12
Three-light ball fitting, tulip shades, lamps, and holders ...	2	11
Three-light spider fitting 12-in. spread shades, etc.	2	14

It is essential that arrangements should be made at the ends of the flexible connecting to plugs, terminals, etc., so that sharp bending may be avoided. This can be done quite simply in a number of ways, but is very usually neglected.

XIV. THE ATTRACTION OF DUST BY FLEXIBLES.

A. A. Campbell Swinton* has shown that the collection of dirt on flexibles is due to electrostatic action, and F. G. Baily† has pointed out that the sign of the potential with regard to the earth is without, or almost without, influence on the result. On both two- and three-wire systems, so long as the switch is on the live side the deposit of dirt will be small, but where it is on the earthed side the deposit will be large, and may extend several inches from the conductor.

With reference to flexible wiring systems, the discoloration of the adjacent walls may be advanced as an objection, but the author would point out that almost any pipe or conduit crossing a horizontal or vertical surface in a room is liable to cause discoloration, which usually takes the form of a light space in the immediate vicinity of the pipe with a dark area beyond it. This is doubtless due to the action of the air-currents when passing the obstruction.

In conclusion, with the scant leisure and the very limited time at the disposal of the author, the compilation of this paper would have been impossible but for the kind co-operation of friends, colleagues, and students. In addition to the acknowledgments already made in the text, the author wishes to express his indebtedness to the following gentlemen :—

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Messrs. J. Hubner and F. Sinnatt, for assistance in the experimental work on rubber.

Mr. W. Grant, for detailed reports on a large number of old and new flexibles.

Mr. J. Lustgarten, for high-tension tests.

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* *Electrician*, vol. 45, 1900, p. 17.

† *Ibid.*, p. 604.

To the Committee of the School of Technology, Manchester, in the laboratories of which Institution the tests were carried out.

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APPENDIX A.

AMERICAN REGULATIONS (NATIONAL ELECTRICAL CODE, 1905).

1. *Installation Rules for Flexible Cord.*

(*a*) Must have an approved insulation and covering.

(*b*) Must not be used where the difference of potential between the two wires is more than 300 volts.

(*c*) Must not be used as a support for clusters.

(*d*) Must not be used except for pendants, wiring of fixtures, portable lamps or motors, and portable heating apparatus.

The practice of making the pendants unnecessarily long and then looping them up with cord adjusters is strongly advised against. It offers a temptation to carry about lamps which are intended to hang freely in the air, and the cord adjusters wear off the insulation very rapidly.

For all portable work, including those pendants which are liable to be moved about sufficiently to come in contact with surrounding objects, flexible wires and cables especially designed to withstand this severe service are on the market, and should be used.

(*e*) Must not be used in show windows.

(*f*) Must be protected by insulated bushings where the cord enters the socket.

(*g*) Must be so suspended that the entire weight of the socket and lamp will be borne by some approved device under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

This is usually accomplished by knots in the cord inside the socket and rosette.

2. *Materials and Construction for Flexible Cord.*

(*a*) Must, except as required for portable heating apparatus, be made of stranded copper conductors, each strand to be not larger than No. 26 (16 mils.) or smaller than No. 30 (10 mils.) B. & S. gauge, and each stranded conductor must be covered by an approved insulation and protected from mechanical injury by a tough braided outer covering.

(*b*) Each stranded conductor must have a carrying capacity equivalent to not less than a No. 18 (40 mils.) B. & S. gauge wire.

(*c*) The covering of each stranded conductor must be made up as follows :—

(1) A tight close wind of fine cotton.
(2) The insulation proper, which shall be waterproof.
(3) An outer cover of silk or cotton.

The wind of copper tends to prevent a broken strand puncturing the insulation and causing a short circuit. It also keeps the rubber from corroding the copper, (*d*) The insulation must be solid at least one thirty-second of an inch thick and must show an insulation resistance of fifty megohms per mile throughout two weeks' immersion in water at 70° Fahrenheit, and stand the following tests.

Each foot of the completed covering must show a dielectric strength sufficient to resist throughout five minutes the application of an electro-motive force proportionate to the thickness of insulation in accordance with the following table :—

Breakdown Test on 1 Foot.

Thickness in 64ths inches.	
1	3,000 volts A C.
2	6,000 ,, ,,
3	9,000 ,, ,,
4	11,000 ,, ,,

(*e*) The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out, and where cotton is used it should be impregnated with a flameproof paint, which will not have an injurious effect on the insulation.

(*f*) Flexible cord for use on portable lamps, small motors, or any device which is liable to be carried about must meet all the above requirements as to construction and thickness of insulation, and in addition must have a tough braided cover over the whole. There must also be an extra layer of rubber between the outer cover and the flexible cord, and in moist places the outer cover must be saturated with a moisture-proof compound. In offices, dwellings, or in similar places where the appearance is an essential feature a silk cover may be substituted for the weather-proof braid.

For Portable Heating Apparatus (applies to all smoothing irons, etc., and to any other device requiring more than 250 watts).

(*g*) Must be made up as follows :—

(1) Conductors must be of braided copper, each strand not to be larger than No. 30 (10 mils.) or smaller than No. 36 (5 mils.) B. & S. gauge.

When conductors have a greater carrying capacity than No. 12 (80 mils.) B. & S. gauge they may be braided or stranded with each strand as large as No. 28 (12·2 mils.) B. & S. gauge. If stranded, there must be a tight, close wind of cotton between the conductor and the insulation.

(2) An insulating covering of rubber or other approved material not less than one sixty-fourth inch in thickness.

(3) A braided covering not less than one thirty-second inch thick composed of best quality long fibre asbestos containing not over 5 per cent. of vegetable fibre.

(4) The several conductors comprising the cord to be enclosed by an outer reinforcing covering not less than one sixty-fourth inch thick, especially designed to resist abrasion and so treated as to prevent the covering from fraying.

APPENDIX B.

French Regulations (Syndicat Professionel des Industries Electriques, January, 1906).

1. *Insulation of Flexible Conductors.*

(*a*) *Medium Insulation.*—This should consist of a layer of cotton and a layer of natural rubber or a layer of vulcanised rubber. Mechanical protection to consist of a layer of silk or glazed braid.

(*b*) *High Insulation.*—This should comprise two layers of natural rubber or two layers of vulcanised rubber. Mechanical protection is to be secured by silk braid or glazed braid.

(*c*) *Flexible Conductors for Pendants.*—Flexibles employed for wiring pendants should be insulated by one or two layers of rubber protected by silk braiding and a plaiting treated with paraffin. This applies to installations up to 110 volts, and the insulation resistance should be 600 megohms per kilometer ($\frac{5}{8}$ mile) after twenty-four hours' immersion in water at 15°C. For 200-volt circuit the insulation should comprise two vulcanised rubber layers, a silk braiding, and a paraffin wrapper giving an insulation resistance of 600 megohms per kilometer. These specifications are given merely as an indication of the practice to be adopted, and there is no obligation to comply with them where the conditions do not admit of doing so.

(*d*) *Nature of Insulation.*—At the time of fixing the insulation of conductors should satisfy the specification; the insulating material should not crack, and conductors covered by an insulating material containing sulphur should be tinned.

Rubber used for insulation may be classed:—

(1) Para rubber tape made of pure Para rubber.
(2) Natural rubber made of indiarubber vulcanised after application.
(3) Vulcanised rubber used as a sheath and vulcanised during the process of manufacturing the wire. If there are several layers, these should be perfectly adherent to one another.

(*e*) *Conductors* for flexible wires or cables should be stranded, each strand being not more than 0·25 mm. (10 mils.) diameter.

(*f*) *Conditions of Installation.*—Conductors having only a "*medium*" insulation can only be employed where the pressure is below 150 volts. When the pressure is 150–250 volts between the conductors or 155–500 in relation to earth, the insulation resistance should not be less than 600 megohms, and when the pressure between the conductors is between 250 and 500 volts the insulation resistance should be 1,200 megohms at least. The use of metallic ligatures for multiple conductors is forbidden.

For joining flexible wires to one another and to conductors it is recommended to employ rosettes with screwed contacts.

Flexible conductor branchings must be made from the main circuit by means of a contact plug or some similar apparatus.

Regulations other than the above adopted by the Associations françaises de Proprietaires d'Appareils à vapeur ayant un service électrique, the Association des Industriels du Nord, and the Association Normande pour prevenir les Accidents. These rules were drawn up in 1900 and revised in 1903–1904, and are chiefly employed in the North and East of France.

2. *Insulation.*

(1) Para rubber tape made of pure Para rubber and vulcanised without excess of sulphur. At 15° C. (59° F.) and within thirty seconds it ought to be capable of being stretched to six times its length, ten times in succession, without cracking or breaking.

(*a*) "*Medium*" *Insulation.*—This should comprise either (*a*) two layers of Para rubber with necessary braided covering, or (*b*) two layers of "natural" rubber with necessary braiding, or (*c*) one layer of vulcanised rubber, without being watertight. In specifications *a* and *b*, the minimum weight in grammes of rubber per metre of single wire is the same as the diameter of the core in millimetres. In specification *c*, the thickness of the rubber layer should be at least $(0{\cdot}5 + 0{\cdot}1\,d)$ mm. (d being the diameter of the core in mm.). Mechanical protection is to consist of a layer of silk or glazed cotton.

(*b*) "*High*" *Insulation* (300 megohms).—This should comprise two layers of rubber, of which one at least should be vulcanised and completely waterproof, the minimum thickness of which should be $(0{\cdot}7 + 0{\cdot}1\,d)$ mm.

(*c*) "*Very High*" *Insulation* (600 megohms).—This should comprise two layers of vulcanised rubber, completely waterproof, of the following minimum thickness $(0{\cdot}9 + 10{\cdot}0\,d)$ mm.

(*d*) *Flexible Wires for Pendants.*—Flexibles for this purpose corresponding to specifications *a* and *b*, the minimum insulation thickness may be reduced one-third, provided the external protecting layer is of braided silk treated with wax.

Multiple flexible conductors must not be employed in dwellings except in perfectly dry places where explosive mixtures are neither generated nor accumulated, and they should be at least 3 mm. (0·12 in.) from walls and ceilings.

Multiple conductors should be avoided as far as possible for connections with commutators and circuit breakers. In places where there is inflammable dust or nap which becomes attracted to the wires this method will not be allowed.

When there is risk of movable flexible wires getting soaked with water (as in dye-works, breweries, etc.), they should be inserted in a rubber tube hermetically sealed at its two extremities.

APPENDIX C.

GERMAN REGULATIONS (ISSUED BY THE VERBAND DEUTSCHER ELEKTROTECHNIKER, JUNE, 1901; AMENDED JUNE, 1904 AND 1905).

1. Flexibles may be employed with two classes of insulation, viz.: (i) rubber put on spirally in the form of tape, (ii) rubber in the form of a continuous sheath. Taped rubber flexibles may only be used in dry living rooms for pressures up to 125 volts. They may not be used under dress material or for portable fittings, and may not be installed in cellars, under floors, in bedrooms, or halls. The vulcanised rubber may, however, be used up to 1,000 volts for fixed apparatus and up to 500 volts for portable purposes.

STANDARD REGULATIONS FOR TAPED AND VULCANISED RUBBER FLEXIBLES.

2. (*a*) *Taped Rubber Flexibles.*—This insulation may be applied to conductors of from 1 to 4 sq. mm. (0·0015 to 0·0062 sq. in.) in cross-sectional area.

The conductors to consist of stranded tinned copper wires of not more than 0·3 mm. (12 mils.) diameter. The conductor is to be spun over with cotton and lapped with unadulterated pure Para strip, which is to be unvulcanised. The overlap of the tapes is to be at least 2 mm. (0·08 in.). The weight of the rubber covering for 100 metres (109·3 yds.) length of single untwisted conductor is not to be less than the following:—

TABLE XXIII.

Weight of Insulation on Taped Rubber Flexibles (V.D.E.).

Conductor Section.		Weight of Rubber Covering.	
Sq. mm.	Sq. in.	Grammes per 100 Metres.	Lbs. per 100 Yds.
1·0	0·00155	130	0·262
1·5	0·00232	155	0·313
2·5	0·00388	190	0·384
4·0	0·00620	230	0·464

Note.—For the purpose of testing for the above the mean of five weighings of one-metre sample lengths is to be taken. Tolerance for dimensions and weight, 5 per cent.

Over the rubber tape each single conductor must have a cotton covering, and over this a braiding of insulating material such as silk or Glacé cotton, which must be non-inflammable.

These conductors must, in a dry condition, be capable of satisfactorily withstanding a test pressure of 500 volts alternating for half an hour.,

(*b*) *Vulcanised Rubber Flexibles.*—These are permissible in sections of 0·75 to 6 sq. mm. (0·0011 — 0·0093 sq. in.).

The conductors to consist of stranded tinned copper wire of not more than 0·3 mm. (11·7 mils.) diameter.

The conductors are then to be spun over with cotton and enclosed in a water-tight sheath of vulcanised rubber. The quality of the rubber sheath must be such that it will after twenty-four hours' immersion in water successfully withstand half an hour's application of 2,000 volts alternating between the conductor and the water. The temperature of the water to be not more than 25° C.

The thickness of the rubber covering to be as follows:—

Table XXIV.

Thickness of Rubber Covering for Vulcanised Flexibles (V.D.E.).

Cross-sectional Area of Conductor.		Thickness of Rubber Covering.			
		Maximum.		Minimum.	
Sq. mm.	Sq. in.	mm.	mils.	mm.	mils.
0·75	0·00116	1·1	43	0·8	31
1·0	0·00155	1·1	43	0·8	31
1·5	0·00232	1·1	43	0·8	31
2·5	0·00388	1·4	55	1·0	39
4·0	0·00620	1·4	55	1·0	39
6·0	0·00930	1·4	55	1·0	39

Note.—Tolerance for dimensions, 5 per cent.

Each single conductor must be provided over the rubber with a protective sheath, the character of which will depend upon the nature of the work for which it is intended.

(*c*) *Flexibles for Portable Apparatus.*—Conductors for portable apparatus must, in addition to the above, be provided with a suitable covering common to both conductors.

(*d*) *Flexibles for Counterweight Fittings.*—The conductors must have a cross-sectional area of 0·75 sq. mm. (0·0016 sq. in.), made up of stranded tinned copper wires of not more than 0·3 mm. (12 mils.)

diameter, covered with cotton and with a vulcanised rubber sheath of 0·6 mm. (24 mils.) wall. The two conductors are to be made up with a suspending string or cord of suitable material, and are to receive a common braiding of cotton, hemp, silk, or similar material. The suspending cord can be double and on both sides of the conductors: if it is metallic it must be itself covered with cotton or braided. In connecting up the leads should be left longer than the suspending cord. The completed flexibles must be so pliable that single conductors can be worked over pulleys of 25 mm. (1 in.) diameter and twin conductors over pulleys of 35 mm. (1·38 in.) diameter without injury. These flexibles in a dry condition must be able to withstand an alternating pressure of 1,000 volts.

APPENDIX D.

DETAILED EXAMINATION OF SAMPLES OF VULCANISED FLEXIBLE NOW ON THE MARKET.

1. 35/40 *Twin-twisted, Marked 3d. per Yard.*

Outside covering, silk, fine.

Dielectric thickness, 0·41 mm., 16 mils.

Dielectric is vulcanised rubber alone. Joints good. Soft, but has very little elasticity.

Cotton over conductors, which are blackened a good deal.

Will not stretch to twice original length.

12 ins. stretched broke at $15\frac{15}{16}$ ins., $17\frac{1}{4}$ ins., $18\frac{1}{8}$ ins.

It might have stretched a little more than this; it was very difficult to strip off.

Percentage of ash, 60·5.

2. 35/40 *Twin-twisted, Marked 2d. per Yard.*

Outside covering, cotton, strong.

Dielectric thickness, 0·41 mm., 16 mils.

Dielectric is vulcanised rubber alone. Soft, but has very little elasticity.

Cotton over conductors, which are blackened.

Percentage of ash, 60·8.

12 ins. stretched broke at 19 ins., $18\frac{3}{8}$ ins., $16\frac{7}{8}$ ins.

Difficult to strip off.

3. 35/38 *Twin-twisted, Marked 1d. per Yard.*

Outside covering, silk.

Inside covering, unwoven cotton lapped round.

Dielectric thickness, 0·65 mm., 26 mils.

Dielectric is pure and vulcanised rubber. One of the longitudinal joints is split. The conductor is badly decentralised. Cotton-covered wires blackened.

Elongation on 12 ins., $1\frac{3}{8}$ ins.

12 ins. stretched broke at $47\frac{1}{4}$ ins., $52\frac{1}{2}$ ins.

Percentage of ash, 57·7.

4.[*] *No. and Gauge of Strands*, 35/40.

Braid, maroon cotton, well woven.
Dielectric thickness, 31 mils.
Dielectric thickness should be 30 mils.
Pure rubber, none.
Rubber, ZnO, etc., good even layer } Soft and elastic.
Vulcanised rubber, thin layer
Elongation on test of 12 ins., $\frac{3}{8}$ in.
12 ins. stretched broke at 4 ft. 5 ins.
Percentage of ash, 37·1.

5. *No. and Gauge of Strands*, 35/40.

Braid, maroon silk, well woven, strong.
Dielectric thickness, 34 mils.
Dielectric thickness should be 30 mils.
Pure rubber, thin clean layer
Rubber, ZnO, etc., good clean layer } Moderately soft and elastic.
Vulcanised rubber, thin layer
Elongation on test of 15 ins., broke on test after $\frac{3}{4}$ hour.
12 ins. stretched broke at 31 ins.
Percentage of ash, 34·6.

Remarks.—Double layer of silk thread wound round wires. This flex appears to be very good with the exception of the vulcanised rubber, which cracks and comes off in small pieces when stretched.

6. *No. and Gauge of Strands*, 35/40.

Braid, maroon cotton, well woven.
Dielectric thickness, 32·5 mils.
Dielectric thickness should be 33 mils.
Pure rubber, none.
Rubber, ZnO, etc., thin layer } Soft and elastic.
Vulcanised rubber, thin layer
Elongation on test of 12 ins., $\frac{13}{16}$ in.
12 ins. stretched broke at 45 ins.
Percentage of Ash, 60.

7. *No. and Gauge of Strands*, 70/40.

Braid, maroon silk.
Dielectric thickness, 12 mils.
Dielectric thickness should be 35 mils.
Pure rubber, none.
Rubber, ZnO, etc., none.
Vulcanised rubber, very thin layer. Inelastic.
Elongation on test of 12 ins., will not stand test.
12 ins. stretched broke at 21 ins.
Percentage of ash, 63·4.

Remarks.—Rubbish.

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[*] Nos. 4–8 extracted from a large number of reports kindly furnished by Mr. W. W. Lackie from tests at Glasgow.

8. *No. and Gauge of Strands*, 35/40.

Braid, red silk.
Dielectric thickness, 31·5 mils. to 35·5 mils.
Dielectric thickness should be 30 mils.
Pure rubber, none.
Rubber, ZnO, etc.
Vulcanised rubber } Thin, dirty, a little hard, and not very elastic.
Elongation on test, will not stand elongation test.
4 ins. stretched broke at $9\frac{3}{4}$ ins.
Percentage of ash, 72·8.

DETAILED EXAMINATION OF C.M.A. FLEXIBLES.

TWIN-TWISTED 23/36.

INSULATED WITH PURE RUBBER, SEPARATOR, AND V.I.R.

	Firm A.	Firm B.	Firm C.	Firm D.
Outside covering ...	Silk	Cotton	Silk	Cotton
Minimum dielectric thickness in mm....	0·86	0·9	0·87	0·65
Minimum dielectric thickness in mils....	34	36	35	26
Condition of strands	slightly discoloured	slightly discoloured	slightly discoloured	slightly discoloured
Percentage of ash ...	48·1	48	44·6	42·1
Elongation on 12'' length after stretching to 24'' for 24 hours (3 samples)	$\frac{5}{8}''$	$\frac{7}{8}''$	$\frac{3}{8}''$	$\frac{1}{2}''$
12'' length broke at	5' 3''	5' 1''	4' 7''	5' 4''

DETAILED EXAMINATION OF AMERICAN "CODE" WIRE FLEXIBLES.

Note.—The specimens examined were only 3 ins. long.

C_1, *Marked* 18 *Reinforced Cord, New.*

Outside covering, cotton braid, heavily coated with preservative; then coated over twin cotton-covered leads with what looks like vulcanised bitumen.* Cotton braid over each insulated conductor; then vulcanised bitumen and rubber over cotton-covered conductors, which are badly blackened.

Dielectric thickness, 0·8 mm., 31·5 mils.

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* Presence of bitumen confirmed by analysis.

The conductor is, however, badly decentralised, so that the thickness is much less than this in many places.

Percentage of ash, 60·7 for outside layer.

„ „ „ 62·3 for inside layers.

There is a considerable variation in the gauge of the strands.

The outside layer of vulcanised bitumen has evidently been put on in a plastic condition, as it completely fills up the interstices between the insulated conductors.

C_2, *Marked* 18 *Old Code, Reinforced Cord.*

Outside covering, cotton braid, no coating of preservative; then material which looks like vulcanised rubber over cotton-covered insulated conductors. Cotton over insulated conductors; then vulcanised rubber over cotton-covered conductors, which are also badly blackened.

Dielectric thickness, 0·36 mm., 14 mils.

Joints bad. The dielectric yields suddenly and then breaks when stretched.

Percentage of ash, 55·4 for outside layer.

„ „ „ =71·2 for inside layers.

Gauge of the strands variable.

C_3, *Marked* 18 *Old Code, Cotton-covered Cord.*

Outside covering, cotton braid; then material which looks like vulcanised bitumen *; then cotton over conductors, which are badly blackened.

Dielectric thickness, 0·72 mm., 28·3 mils.

The thickness is uncertain, as the material was badly cut into by the braid.

Percentage of ash, 62·7.

Wires fairly uniform in gauge.

C_4, *Marked* 18 *New Code, Cotton-covered Cord.*

Outside covering, cotton braid; then material which looks like vulcanised rubber, but might also be vulcanised bitumen.

Cotton over conductors, which are somewhat blackened.

Dielectric thickness, 0·8 mm., 31·5 mils.

Percentage of ash, 63·7.

Large variation in the gauge of the strands.

C_5, *Marked* 18 *New Code, Silk-covered Flexible.*

Outside covering, silk braid; then vulcanised bitumen (?); then cotton over conductors, which are very badly blackened.

Dielectric thickness, 1 mm., 39·3 mils.

This is rather uncertain; conductor slightly decentralised.

Percentage of ash, 62·8.

Gauge of strands fairly uniform.

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* Presence of bitumen confirmed by analysis.

C_6, *Marked* 18 *Old Code, Silk Flexible.*

Outside covering, silk.
Dielectric looks like vulcanised rubber.
Dielectric thickness, 0·41 mm., 16 mils.
Thickness is not uniform.
Cotton over conductors, which are badly blackened.
Percentage of ash, 62·2.
Gauge of strands, fairly uniform.

C_7, *Marked* 22 *Silk-covered. Small Insulation.*

Outside covering, silk braid; then soft, inelastic, putty-like material, which cannot be vulcanised rubber, as the conductors are quite clean.

Cotton over conductors.
Dielectric thickness, 0·28 mm., 11 mils.
Percentage of ash, 69.

APPENDIX E.

DETAILED EXAMINATION OF SAMPLES OF OLD FLEXIBLE.

VULCANISED FLEXIBLE.

1. 35/38 *Twin-twisted.*

Outside covering, cotton braid (black).
Inside ,, ,, ,, (blue).
Dielectric thickness, 0·53 mm., 21 mils.
Dielectric is vulcanised rubber, which is soft and fairly elastic.

Cotton over conductors, which are extremely brittle, and are blackened.

Not enough to stretch, but would certainly elongate to four or five times original length before breaking.

2. 35/38 *Workshop.*

Outside covering, strong cotton braid.
Inside ,, ,, ,, ,,
Then the rubber-covered conductors, laid up with unwoven cotton.
Dielectric thickness, 0·74 mm., 29 mils.

Dielectric is vulcanised rubber and rubber separator. Rubber is hard and inelastic. The conductors are tinned but blackened, and covered with unwoven cotton.

Two samples { 12 ins. stretched broke at $19\frac{1}{4}$ ins.
,, ,, ,, ,, $18\frac{3}{8}$ ins.
Percentage of ash, 54·5.

3. 35/38 *Twin-twisted.*

Outside covering, cotton braid.
Inside ,, ,, ,,
Then unwoven cotton laid up with rubber-covered conductors.
Dielectric thickness, 0·77 mm., 30 mils.

Vulcanised rubber alone seems fairly elastic and strong.

Cotton over conductors, which are tinned and slightly blackened.

Elongation on 12 ins. stretched to 24 ins., 1⅞ ins.

12 ins. stretched broke at 40½ ins.

Percentage of ash, 53.

35/40 *Workshop.*

Heavy jute braid coated with preservative; this braid is badly finished; then unwoven jute laid up with cotton-covered conductors. There is no rubber of any kind. Conductors fairly clean.

5. 35/50 *Workshop.*

Outside covering, cotton braid, strong.

Inside covering, cotton braid, strong.

Then unwoven cotton laid up with conductors. The two braids are well coated with preservatives.

Dielectric thickness, 0·5 mm., 19·7 mils.

Dielectric is vulcanised rubber and rubber separator. Soft and seems moderately elastic. Decentralised in places.

Strands very brittle. Wires blackened.

Percentage of ash, 42.

Elongation on 12 ins., ⅞ in. 12 ins. stretched broke at 51½ ins.

6. 26/38 *and* 22/38 *Twin-twisted.*

Outside covering, cotton braid.

Dielectric thickness, 0·73 mm., 28 mils.

Dielectric is rubber separator only, which is very brittle, and crumbles away on bending. This is an example of what inferior material can come to.

Cotton over conductors, which are blackened. Note the unequal number of strands in the two sides.

Will not stretch.

Percentage of ash, 47.

7. 35/40 *Twin-twisted.*

Outside covering, cotton braid, fine.

Dielectric thickness, 0·39 mm., 15·3 mils.

Dielectric is rubber separator only, which is soft like putty.

Cotton over conductors, which are black.

Will not stretch.

54·3 per cent. ash.

8. 35/40 *Twin. June,* 1898, *till Oct.,* 1906.

Outside covering, cotton braid.

Dielectric thickness, 0·62 mm., 24·4 mils.

Dielectric is vulcanised rubber.

Soft, and has little elasticity.

There is also an extremely thin layer of pure rubber.

Conductors black.

Will not stretch to twice original length.

12 ins. broke at 16⅜ ins.

It was very difficult to strip off.

57·5 per cent. ash.

PURE RUBBER-TAPED FLEXIBLES.

9. 39/39 *Twin. Dec. 14th,* 1883, *till Aug.,* 1905.

Outside covering, cotton braid; then cotton braid on each insulated conductor.

Dielectric thickness, 0·65 mm., 25·5 mils.

Dielectric pure rubber, soft, and has lost its elasticity.

Cotton over conductors.

Conductors clean.

10. 35/40 *Workshop.* 1888 *to date.*

Outside covering, strong cotton braid, well coated with preservative; then unwoven cotton laid up with insulated conductors; then unwoven cotton over rubber.

Dielectric thickness, 0·1 mm., 4 mils.

Dielectric is pure rubber, and has evidently been put on under considerable tension. It has lost its elasticity.

Cotton over conductors, clean.

11. 35/40 *Twin.* 1889 *to date.*

Outside covering, silk braid.

Unwoven cotton laid up with conductors. Unwoven cotton over insulated conductors.

Dielectric thickness, 0·08 mm., 3·1 mils.

Dielectric is pure rubber.

Soft and slightly elastic still.

Cotton over conductors.

Conductors clean.

12. 35/40 *Twin.* 1886 *to date.*

Outside covering, cotton braid.

Inside covering, cotton braid (thicker).

Dielectric thickness, 0·22 mm., 8·7 mils.

Dielectric is pure rubber, hard, strong, but inelastic.

Cotton over conductors.

Conductors clean.

13. 37/39 *Twin.* 1890 *to date.*

Outside covering, cotton braid; then two layers of unwoven cotton.

No rubber.

Wires untinned. Clean.

14. 21/38 *Twin.*

Outside covering, silk braid; then two layers of unwoven cotton.

No rubber. Wires not tinned. Clean.

DISCUSSION.

Mr. S

Mr. C. P. SPARKS: I have read the paper with much interest, but I have found the mass of detail put at our disposal somewhat difficult to digest in the time I have had to consider the subject. On behalf of the Wiring Rules Committee I wish again to tender to Professor Schwartz our special thanks. Last year, when we had the question of revision of the Rules before us, we were met with the want of data with regard to the flexibles then in common use, and he gave us his very hearty co-operation in elucidating certain points. While I am on this point I should like to say that some five years ago, when the Wiring Rules were under revision, we were faced by the fact that there was no test for flexibles, and after consultation with the manufacturers, a test was proposed which was admittedly inadequate, but it was better than having no test at all. It consisted in specifying a pressure test at 1,000 volts. At that time we were dealing with pure rubber flex, and it being impossible, owing to the absorptive power of pure rubber, to specify an immersion test, we specified what was equivalent to a dry test. Further experience during the last few years showed us that this test was not effectual; and in the last edition of the Rules which has just been issued it will be found that the standard has been raised, and that in the place of testing samples, every hank is to be pressure tested to 1,500 volts for a quarter of an hour. In the meantime, the Cable Makers' Association have produced a vulcanised flex, which is being largely used, and in that case we specify a pressure test, after twenty-four hours' immersion in water, of 1,500 volts for a quarter of an hour. Professor Schwartz has drawn attention to the Rules existing in other countries. Referring to his abstracts, it will be seen that the American rule for the vulcanised flex is a minimum thickness of dielectric of 31 mils. In the Institution minimum we have adopted the Cable Makers' standard of 34 mils. The American pressure test is that after two weeks' immersion in water it is to be tested at 6,000 volts. In our case, after twenty-four hours' immersion in water, the pressure test is 1,500 volts. In Germany the minimum insulation of vulcanised flex is 31 mils., with a pressure test of 2,000 volts after twenty-four hours' immersion in water. In France no dielectric thickness is specified, and there is an insulation test only after twenty-four hours' immersion in water. The author has pointed out the relative merits of vulcanised *versus* pure rubber flex. My own opinion is in favour of the pure rubber flex. No doubt the attraction of vulcanised flex is the fact that the pressure test can be made and the insulation test taken when the cable is in water, and more exacting tests can be made that on pure rubber flex. But the durability of pure rubber flex made with high-class material is, through the absence of sulphur and the smaller deterioration at moderate temperatures, very much in its favour. English experience with flexibles has been largely based upon this material, and the vulcanised flexible must be considered as being upon trial. On page 70 tests are

Mr. Sparks. given of the mechanical strength of flexibles, tests that were carried out to assist the Committee; while on page 74 some pressure tests are given. We were glad to see that the specimens of flex made to the then Institution Rules came out well above the average. For instance, with regard to the breaking mechanical strength, it failed after 18,100 bends, while it stood a test pressure up to 21,500 volts. Under paragraph 44 of the new Wiring Rules, laying down rules for both pure and vulcanised flex, attention is drawn to the desirability of using pure rubber flex with pendants, or in any position where the wires are often bent. The next point I would like to mention is on page 36, where the question of the grouping of flexible conductors is mentioned. The author says, "In mill and factory lighting, moreover, it is impossible for economic reasons to employ only 5-ampere circuits where long aisles are to be lit." I think there is some misunderstanding on that point, because if necessary one can control a 100- or 200-ampere circuit as a whole. At the same time, each individual part, each 5-ampere circuit, can be effectively guarded so far as fusing is concerned. In revising the Rules some five years ago a rule was introduced, which is now paragraph 21 of the new edition, drawing attention to the necessity, in wiring, of limiting the sub-circuit to 5 amperes at 125 volts and 3 amperes at 250 volts. In my opinion that is one of the soundest and most necessary rules that the Institution has ever issued. If it is carefully adhered to the risks that are undoubtedly run with bad flexible, or carelessly handled flexible, are enormously minimised, because a fuse that will carry 5 amperes is well within the limit of safety, as shown by Professor Schwartz's test of smoking or flaming flexibles. It is so well within that limit, and if circuits are reasonably fused the safety of the whole system is assured by subdivision into these sub-circuits.

With regard to the system of wiring, Professor Schwartz mentions the Continental practice. It is only of recent years that any open wiring work has been permitted, either by the Institution or by the Fire Offices in this country. In the Rules which were re-issued some five years ago permission was given in a tentative way for open work to be carried out, and during the last few years this work has grown. Now, under paragraph 46 (*c*) of the new Wiring Rules, more definite instructions are given as to the way in which this work is to be done, and I think with the use of the sub-circuit system there is a very great field for such work, which will widen the use of electricity, and enable it to be used in many cases where the capital cost of wiring the smaller buildings has prevented its use hitherto. On page 82 of the paper mention is made of the price that might be reached per point with open wiring with flexibles. From my experience that point has not only been reached with other systems, but long since passed, namely, from 10s. to 18s. per point, and represents a standard that I am sure the wiring contractor in this part of the world would welcome if he could obtain as a general rule. The cost of work carried out on the open system is going to be far less per point than that indicated.

Mr. Sparks.

Coming to the second part of the paper, I am much interested in the question of rubber and the suggested hysteresis test. My experience of rubber is not of a very scientific kind. For many years I have been principally a user of either fibre or paper cables. Comparing a sample of rubber cable that one gets to-day, I cannot help feeling that we are dealing with an entirely different article to what we were using in the pioneering days of electrical engineering. Whether the raw material has changed, and for this reason it is not possible to make rubber cables to-day as they were made then or not, I do not know; but it appears to me that one cannot buy the same class of cable as that manufactured here in England twenty years ago. Personally, I believe it to be a question of raw material. I hope the rubber makers, will come here, and, without giving away the whole of their trade secrets, throw some light on this matter, because there is a very great want of a reliable test for rubber, not only for the protection of the buyer but also of the seller. The manufacturer in this country is supplying a high-class article, but it is difficult for the buyer in many cases to say, "This cable, although it appears to be 10 or 15 per cent. dearer than another sample, is worth the higher sum." At the moment some of us cannot discriminate; it is only a question of price. And I think the cable makers should help us to draft such a specification that, in the hands of practical men, we can select, and therefore pay for, a better article, instead of relying entirely on the cable maker's reputation.

Mr. Whalley.

Mr. A. WHALLEY: I have read the paper with very great interest, especially the point dealing with the high temperature in lamp-holders, and in the next place the excellent results recorded in tests of C.M.A. flexibles. If such excellent results are obtained under the present specifications, does not this indicate that there is no great need for further tests, which must be very complicated in character, and could only be carried out by those having prolonged experience in the manufacture and testing of rubber goods? As regards conductors, and the question of the conductivity of stranded compared with single wires, I would suggest that Professor Schwartz ignore altogether the diameter and area, but from the resistance and weight of a unit length, multiplied together, obtain a constant for the stranded conductor; then take out of the stranded conductor a single wire (which would be hardened, due to the stranding), and also take a single unstranded wire and obtain similar constants for them. This would show whether there was any change in the conductivity. The question of gauging the thickness of tinning, dealt with in Table IV., is a very difficult one. Speaking generally, as pointed out by the author, a small error in gauging, such as one part in sixty, means, perhaps, a 3 per cent. error, or a one part in forty error in diameter means a 5 per cent. error in the area. Such errors with small wires can easily be produced by simply holding the micrometer in the hand a few minutes, causing expansion of the micrometer. The thickness of the tin, as a rule, can only be measured chemically. On a small wire usually it is less than on a large wire, having to be drawn through the tinning bath, if of normal tem-

Mr. Whalley.

perature, at a greater rate to prevent its being melted, and there is thus a tendency for less tin to be placed on it. This is still generally true. In Table IX. tests are recorded to illustrate the effect of corrosion by sulphur of copper conductors, under conditions of long age, and it is put forward as though the whole of the decrease in tenacity was due to the use of vulcanised rubber. I hardly think the table supports this conclusion. It is easy for the hardening effected in the processes of stranding and of insulating conductors to be greater than any change due to the presence of sulphur outside the copper attacking it. For instance, the percentage extension of a single new tinned wire is 25 per cent. under a breaking stress; of pure rubber flexible, presumably without sulphur, it is 19·5 per cent. on the average; for cotton insulated flexible it is 14·5 per cent. (a loss of 10 per cent. compared with the first figure); while with vulcanised rubber it is 10 per cent. But the breaking stress shows a contrary result, the vulcanised rubber flexible being the strongest of the lot, if we eliminate one very bad sample marked E8. The average breaking load in grammes per square millimetre for pure rubber flex is 19,625, for cotton flex 20,000, and for vulcanised flex 20,500. The author expresses a preference for the use of cotton next to the conductor. This has its advantages and disadvantages. The disadvantages, I think, are that it stiffens the conductor pretty considerably, and next that a high insulation resistance cannot well be obtained with cotton on the conductor. When there is cotton on it it is impossible to get rid, even by gassing, of an almost invisible fluff, and very minute tubes of fibre will cut through the joints or overlap of the pure rubber that is applied to the conductor, and these tubes of fibre lower the insulation.

As regards vulcanised indiarubber itself, I think the author has made a slight slip in mentioning that occasionally as much as 50 per cent. of sulphur is made use of. This could only be approached in such a material as ebonite. The injurious effects of oil, and also copper, are mentioned. Untinned brass is almost as injurious as copper itself. Amongst the numerous causes mentioned of the deterioration of rubber under prolonged heat tests, the effect of copper salts is not included, if the tinning is in any way defective. Preference is expressed by the author, and has also been expressed by Mr. Sparks, for the use of pure rubber flexible, the author preferring pure rubber for high temperature. This fact should not be forgotten, that with a temperature somewhat below 200° F. pure rubber becomes tacky, which condition can also be produced by defects in the tinning of the copper. The exact temperature of tackiness will depend upon the kind of raw rubber used. To show the complicated nature of the subject, it is only necessary to say that there are about forty varieties of Para rubber, and the exact temperature of tackiness is dependent on the nature of the rubber and how it is prepared. Then I should like to say with regard to the proposed hysteresis curve, given in Fig. 10, that for every compound used a temperature coefficient would have to be determined well in advance as the result of a long series of experiments.

Mr. Whalley.

Temperature has an enormous effect upon the results, especially in what the author calls the retractive curve. The mere fact of handling the rubber has an important effect in this direction. I presume that the results given in Fig. 12 are for the pure rubber, separator and jacket in one piece together, and that the percentage extension is taken at 70 per cent. of the breaking stress as in other cases. The figures given at the bottom of this table do not appear to agree with the curves, as similar figures are given for the flexibles produced by firms "C" and "D," but the curves differ at all points. On page 60, in connection with this same table, it is mentioned that "strips" were tested. I presume this does not mean that the insulation was cut from the cable by slitting it with a knife lengthwise. If so, I think most contradictory results would be obtained. It is almost impossible to make that slit with one stroke of the knife, and if this cannot be done jagged points and breaks in the line of cleavage are bound to occur, and these are points of weakness. It is a matter of some difficulty to prepare a sample properly. The insulation should be taken off the conductor as an unbroken tube, great care being taken that the whole of the pure rubber is intact, none being left attached to the copper, otherwise one gets a bad sample which cannot be tested. The interesting point of the curves shown last of all by the author seems to be that with an increase of above 50 per cent. of pure rubber (in the samples tested) no increase is shown either in the tensile strength or in power to resist the prolonged heat of 150° F. The strongest rubber, looking at it from the tensile point of view, was the 48 per cent. mixture, and those that stood the heat the longest were the 40 to 45 per cent. Regarding the acetone test to determine the percentage of resin in rubber, percentages are given, in the paper, which ought not to be exceeded in raw Para rubber and vulcanised rubber; but the amount of moisture in the rubber may easily equal or exceed these figures, so that extreme precautions are required to get rid of this moisture first of all. Merely heating the rubber on heating rolls does not suffice, and figures at least double, and perhaps treble, those mentioned may be obtained by this test. The prominent result of the curves of stretching tests on mixtures containing known percentages of pure rubber seems to be that we have, in the first half of the curves, a lower rate of slope for the lower mixtures, and as the slope increases it indicates a greater percentage of rubber. We get just the same result with the present stretching tests in some Government and other specifications, wherein the percentage of rubber is prescribed as 35, 50, or 60 per cent., and corresponding increases in the stretching test are prescribed also. In the second part of these curves, the retractive portion, the almost horizontal line present in all cases indicates that the tension upon the rubber was changed at a rate greater than it could respond to, since the rubber only began to contract after the tension had been reduced by as much as 30 to 50 per cent. The testing of rubber is evidently an extremely difficult subject, and while of interest to the purchaser, is still more so to the maker, who has to consider the dielectric strength and also the

Mr. Whalley. megohms and life at the same time, but it appears almost impossible to devise any simple test which is reliable, and any increase in the complication of tests would probably increase costs without increasing quality.

Mr. Human. Mr. H. HUMAN: Looking at the matter from the Fire Office point of view, we have in this paper something we have long wanted. The author has been dealing with what we have assumed to be our weakest link, and it is very satisfactory indeed to find that that link is not so weak as we have been in the habit of regarding it. The net result of this very interesting paper is, to my mind, to elevate flex in our estimation. The paper also explains some things which hitherto have been a mystery to me. For instance, when we look into shop windows and see how flex is there used and abused, we wonder how it is we do not get more fires in those places than we actually do. The explanation is really found in this paper. When I have observed a dresser in a shop window playing with live flex in the same way he would play with a blind cord, I have sometimes wondered whether that man has the slightest conception that within that apparently innocent looking cord there is enough energy to knock him head over heels. But, as a matter of fact, we seldom hear of people being injured by shocks when handling live flex; and it seems to me again that the reason for that is to be found in some of the tables in this paper. Looking at Table XV. and Tables XVII. and XVIIA, we find there very extraordinary results. Some of the figures are perfectly astounding. I had no idea that that stuff which we call flex, and which we regard as an enemy of ours, is capable of standing a stress of 26,000 volts. Then again, look at Table XV., and neglecting for the moment those very extraordinary figures at the bottom, if we take the mean of those experiments we get 130,000 double journeys up and down. In endeavouring to arrive at the prospective life of such flex, and taking, let us say, an average of 2 double ups and downs per day for 365 days in the year, which is a very reasonable average, we get a result of something like 170 years as its probable life. But there is something wanting there that even Professor Schwartz is not able to supply, and that is the factor of age. We know very well that rubber, like a great many other things, depreciates with age; and if we could get some factor representing that depreciation and apply it to Table XV., I think we should have to knock off some of those noughts. Then as to the bending effect, although there is considerable variation in Table XVII., the net result is very satisfactory from our point of view, and it certainly puts workshop flex on a high pinnacle. There is, however, something again wanting here that does not seem to me to come into the experiment, and that is the heat due to the lamp. If lamps had been inserted in the holders we should have obtained that effect, but I do not suppose there are many lamps on the market that would stand the thousands of rockings that the holders underwent; but if we had the heat of the lamp on the rubber at that point of bending, it would probably bring own some of these figures. When that form of adjustable pendant

Mr. Human.

first came out many years ago, we Fire Office men were in doubt as to how to regard it. Somebody suggested that the counterweight would throw an additional strain on the terminals of the lamp, but it didn't! Then it was suggested that the frequent running over such a small pulley wheel would lead to the fracture of the very delicate strands of the cable, and that that would lead to incipient arcing, which is the danger we have to guard against. But it doesn't! I say so upon the evidence of these tables, and that is a great relief to our minds. With regard to the question as to whether the rubber should be pure or of the vulcanised order, I must say that my leaning has been towards vulcanised rubber, because I regard it as having much better mechanical strength; it resists moisture better than pure rubber, and, theoretically, it should stand heat better. Then, again, in pure flex the coating of rubber is very thin, whereas in the vulcanised there is a substantial thickness. But the evidence we have had of late upsets that theory altogether, which is due to that little factor, the heat of the lamp. That heat appears to destroy both the vulcanised and the pure rubber; but the pure rubber has this bit of luck, that the cotton comes to its aid, and when the rubber is melted the cotton takes it up, thus maintaining the insulation. Then, again, my friend, Mr. Lester Taylor, who has probably held more post-mortems on electrical fires than any other man in this country, is strongly of the opinion that where flex is used in connection with pendant lamps, pure rubber is the proper thing. Therefore it seems to me that this Institution is well justified in recommending pure rubber in such cases. Where mechanical strength, however, is supreme, then possibly we should adhere to vulcanised. But rubber is one of those mysterious things which is elastic in more senses than one—that is to say, there are few things admitting of greater adulteration. When one visits rubber works, and has to go into the question of the various things they employ, one gets a very long list. Many of those things are doubtless justifiable as strengthening the product, but there are many that have as much relation to rubber as sand has to sugar—mere fillers. When lately discussing the point with a well-known authority, as to whether it would not be possible to get out some standard test of a mechanical nature, such as a stretching test, he said, "No, it is quite possible to produce an inferior rubber that would answer the test at first, but would absolutely fail to do so in the course of a few months." Well, where are we? The fact is we are in the hands of the cable makers, and our only salvation, so far as I can see, is to put ourselves in the hands of those makers who have some reputation to sustain.

Mr. Wansbrough.

E. C. Wansbrough: The general conclusions of the author regarding the advantage of pure rubber over vulcanised have been supported by so many previous speakers, that there is no need for me to discuss them further, but I should just like to say that I entirely agree with them.

The author mentions, in connection with Fig. 4, sundry tests, and amongst other things he shows that the temperature obtained with bare

Mr. Wansbrough. wire is higher than with covered wire; but a bare wire which is freely exposed to the atmosphere will remain at a lower temperature for a given current than the same wire enclosed in a tube of insulation. Perhaps he will kindly clear this point up in his reply.

On page 75 the author pins his faith to a high initial insulation resistance test as being a very safe guide to the real character of the insulation. He says, "This is generally considered of small importance." Rightly so too, inasmuch as it is perfectly easy to obtain high initial insulation resistance with materials that possess very poor durability. In my opinion the test specified in the I.E.E. Rules, if honestly and fairly carried out, would prove of considerable assistance in eliminating poor and defective material. The variations in behaviour under the author's tests were only to be expected, rubber being a natural organic product, liable to slight variations in composition which affect to a considerable degree its mechanical and electrical properties. Hence the necessity on the part of manufacturers for most careful selection of their raw material and rigorous inspection and testing during construction. This is done by the high-class makers, but the present-day craze for cheapness keeps the sale of high-grade guaranteed flex within very narrow limits.

On page 53 some of the extraordinary things are mentioned which go to make up so-called V.I.R. flexible. To my certain knowledge these dangerous compounds have a most extensive sale, and I am greatly surprised that at this late day, surrounded as we are by such a multiplicity of Wiring Rules, they should be allowed. I am hoping that the new Wiring Rules which have been foreshadowed by the President to-night, with their strong preference for pure rubber, will rid us entirely of these undesirable aliens.

Mr. O'Gorman. Mr. M. O'GORMAN: When Professor Schwartz gave the paper the unpretentious title of "Flexibles," I am bound to say I did not expect that we should have such a valuable study upon the subject of testing rubber. I shall carry away from hearing this paper two lessons, and I hope Professor Schwartz will endorse my view: the first, that vulcanised flexible has been tried and found wanting—an opinion, I am glad to say, that has been also re-echoed round the room to-night; the second, that a mechanical test which will sift good rubber compound from bad is within sight. In my experience vulcanised flexible is to be avoided in almost all cases. This conclusion may not, perhaps, be universally held, but I have been led to it after a course of years and after having begun as an enthusiast in its favour. I could give reasons for that opinion, but I think it is too late to enter into them. The author's experiments, as I understand their logical outcome, practically lead to the same result, although they help to show the safety in use of flexibles generally. The objection to vulcanised flexibles is chiefly limited to this: that it is in no part of its design calculated to support a weight for a long time. The soft copper wires—for they should be soft—are liable to be made brittle by being tinned. The vulcanised rubber which is, as a matter of fact, Mr. O'Gorman.

almost invariably under-vulcanised in flexibles, presumably because of the danger of having too much sulphur, which will attack the fine wires, is useless in tension as a weight carrier; and lastly, the braid, which might be gripped in the ceiling rose and in the cord grip of the lamp-holder, is liable to almost indefinite extension because the material under it diminishes in diameter with stretching and so permits the braid to assume a greater length without difficulty. Such a flexible may nevertheless be excellent for portable fittings, provided no cord absorbers or pulleys be used with it. In running up and down over pulleys the rubber, if under-vulcanised, acts as a sort of lubricant between the copper strand and the braid; it becomes deformed and does not seem to recover. This appears almost universal in thickly coated vulcanised flexibles. I have seen expensive C.M.A. flexible replaced with improved results by very much cheaper material, which was certainly not waterproof and was undoubtedly covered with inferior pure rubber of African origin. I have seen this happen in damp places—for instance, in a paper mill, than which there is nothing damper—where plain pure rubber and cotton covered flexible was far better in performance. Part of the result is ascribable to the important effect pointed out by the author of the heat of the lamp-holder on the under-vulcanised rubber. A minor point of great interest which has been brought out by the lecturer's experiments is the existence of the persistent low-current arc between the members of a pair, to which vulcanised rubber flexibles are more prone than pure rubber.

Even after all the work done by the author we still have to find a satisfactory test for flexibles. Our test is to maintain 1,500 volts between members of a pair, but we have seen to-night that all sorts of flexibles, good and bad, will stand 6,000, 7,000, 8,000, and 9,000 volts, so that 2,000 volts is the sort of test which may amuse the tester but will not discriminate between good and bad flexibles. It is better than nothing in one respect, namely, that it picks out those little broken strands which poke their way through the rubber and would not be detected because of the absence of the immersion test. In spite of these remarks I am sure we have done rightly in the Wiring Rules Committee in saying that houses may be wired entirely with this untestable material. The author has mentioned that the tensile strength of the core is diminished by temperature, and I take it he leaves it to be implied that this is not a permanent diminution; it simply occurs when the material is hot. My name has been associated, in flattering terms, with the flexible at the end of Table XV., which has had an extraordinarily long life. I was very enthusiastic on the subject, and I think called for it in the first place, but the people to whom the credit is due are undoubtedly the makers, the British Insulated Wire Company. I have tried it very severely in practice for, I think, eighteen months or so in a differential pulley cord absorber, and it stands the test very well; in fact it stands tests which no other flexible has ever stood. It is noteworthy that this

Mr. O'Gorman.

material is, owing to its very recentness, excluded from use under our new Wiring Rules on the score of lack of conductivity, but that is the sort of thing for a permanent Wiring Rules Committee to deal with. I do not doubt but that it may on special occasions be admitted.

The author asked a question as to why twenty-four hours is used in the stretching rubber test. I was one, I think, of quite the early votaries of the stretching test of rubber, and I am glad to see that his work leads to a more scientific style of stretching test. Although Mr. Human was informed by some person—who, I presume, is antagonistic to the testing of rubber by the buyer—that a stretching test was useless because he could obtain *any* stretching result with a material that would be worthless in three months, I greatly doubt whether this rapid deterioration of such a material would be obtained commercially in conjunction with the good electrical test usually required; but that remains to be seen. I daresay Professor Schwartz will make a study of the relative rates of decay of the good and bad rubbers of which he gives curves, because that will make his tests even more important. He is, I think, in favour of the stretching method, and I believe it to be the only practical way of testing cables at all, except the method of lengthy immersion, which is too slow and expensive. A twenty-four hours continuous stretch of rubber is made to ensure that the temperature of the sample is the same as the temperature of the air, otherwise it is difficult to get at the temperature of the sample. One cannot get inside it, and so care must be taken that the whole of the test lasts for twenty-four hours. The temperature of the room then gives that of the cable. As regards speed of stretching, which I agree is important, we have always used a very slow speed worm-wheel arrangement, and I think the time of stretching is about six seconds; at any rate it is nearly a constant speed and comparative as between various samples. Mr. Sparks referred to a subject on which I wish to strengthen his opinion in every possible way. He stated that the importance and advantage of having a stretching test which really indicates the quality of rubber does not solely advantage the buyer or the consulting engineer. It is of value to the maker, who wants us to distinguish good from bad. It relieves us from the necessity of relying absolutely upon the name of the maker. Moreover it is good for the industry to give a chance to the people who are building up a cable business by making good stuff, even though they have not years of history behind them.

Mr. Connolly.

Mr. J. CONNOLLY (*communicated*): I must in the first place congratulate Professor Schwartz on having made a distinct addition to the information available on this subject, and while it is quite evident to any one interested who has seriously studied his paper that the last word has not yet been said on the question of flexibles or of indiarubber insulation, I am of opinion that he has made an important advance towards solving the problem of distinguishing between good and bad, between what will endure and what will perish.

I would give the first place in importance to the hysteresis curves

Mr. Connolly.

shown in Fig. 12. Tests, similar to those on which these results are based, have been used on a rough scale by manufacturers of vulcanised elastic thread, who place great confidence in estimating the quality of the thread by observing its tractile strength against varying loads. I deduce from his results that the curves for inferior material will be found outside the range of the curves for good material, and will fail, either on the side of extensibility or of breaking load, or of both. I think that similar experiments on the insulation of larger size wires and cables are desirable. I hope they will be carried out soon, and that a good practical and reliable test will be the outcome.

I would place second in importance the results shown by the heating tests described on pages 54 to 56, and also further experiments made by Professor Schwartz on compounds with definite percentages of indiarubber in their composition, which I think prove beyond doubt that by subjecting samples to a heat of between 70° and 100° C., or any convenient heat below the melting-point of sulphur, for several days, and examining the fall in their elasticity and strength, it will be possible to foretell their comparative durability, and to place them in the exact order of their merit.

The so-called Admiralty heating tests are quite misleading and ought to be abolished. It is a physical impossibility for the ideal cable covering having a layer of unvulcanised pure indiarubber without any trace of sulphur next to the wire to stand this test, as this rubber becomes permanently soft, at a much lower heat, while if the pure indiarubber is vulcanised, which is not really as good, it may pass the test.

With respect to chemical tests, I do not place any reliance on the author's recommendation. The only simple and reliable test that the average person can carry out is the ignition test, which determines the approximate amount of mineral matter in a compound. All other tests should be left to the chemist expert in examining indiarubber, and even his deductions should be regarded with a large amount of reserve. For instance, the acetone tests will not determine, as the author thinks, whether Para rubber has been used or not. It is quite possible to adulterate very largely with vulcanised oil substitutes, which are not soluble in acetone, and so obtain a fictitious result. Mineral oils that may have been used in the manufacture of recovered indiarubber, some oxidised oils, and free sulphur are all soluble in acetone; the time recommended of five hours is not sufficient to extract all the soluble matter in many cases. The whole matter is so complicated that it does not appeal to the man in search of simple and reliable tests.

With respect to insulation tests, I think that the Institution test of exposing the cord for a limited time to the vapour arising from boiling water and then subjecting to pressure is of no use whatever, as quite inferior material will pass the tests easily. I think that we should make up our minds to dispense altogether with insulation tests for conductors insulated with lappings of pure indiarubber, and rely upon other observations in determining their quality. Tested dry, the results are

Mr. Connolly.

quite unreliable, and immersion in water not only lowers but permanently destroys the insulation on account of the creeping of water between the layers, which moisture cannot subsequently be removed.

Flexibles with vulcanised indiarubber should be tested under water before finishing, in the same way and with the same care as wires and cables, and both an insulation and a pressure test should be used. It is our invariable custom to test flexibles in this manner, and we find that the insulation of a covering free from faults actually improves after prolonged immersion.

In talking of pure indiarubber, there is a good deal of confusion, both in the author's paper and elsewhere, in distinguishing whether vulcanised or unvulcanised indiarubber is meant.

There is very little unvulcanised pure indiarubber used nowadays in covering wires, probably none at all for flexibles; the rubber is always more or less toughened or surface vulcanised by the cold cure process, and it is for the manufacturer to determine the best thing to use in this respect. I do not think the author's hysteresis loops will be of any use in this direction. The best thing the user can do is to see that a substantial thickness has been used in at least two layers put in with a moderate tension, and that the layers are fairly adhesive to one another and do not unwrap or fly back when the outer coverings are removed.

With respect to some of the general questions raised in the author's paper: damage to workshop flexible by the use of oily waste can be provided against, as we can easily provide a flexible covering that is oil-proof.

We always nowadays twist or strand the fine wires used in making up flexibles, and never use straight wires.

We are now making a flexible cover with an indiarubber tube in place of the usual fibrous outer covering; we consider that this tube prevents the indiarubber actually used for insulating purposes from being exposed to external influences and prevents the possibility of electric osmosis. It will also act as a flexible substitute for iron pipes in a waterproof system.

I have no doubt that the gymp flexible, as described by the author, will be very useful in special cases for running over small pulleys, but its use will be limited on account of its relative low conductivity and consequent loss of voltage if a long length has to be used. With respect to the bending tests, I am of opinion that flexibles having a double braid, the first braid being of soft cotton, would give results very superior to flexibles having only one braid. The cotton covering next to the wires has been dispensed with in the C.M.A. vulcanised flexible, as it was considered a potential source of danger in attracting moisture to the strands and did not serve any essential purpose.

With respect to tying knots in flexibles, inside the ceiling roses and elsewhere, I think this a great mistake and should not be allowed. It is putting an unnatural and permanent strain on the covering, and other means ought to be found to support the flexible and keep the strain off the terminals. With this object in view we have devised a nipple of

Mr. Connolly.

soft indiarubber that will answer the purpose and at the same time effectually seal the entrance to the ceiling rose.

I quite approve the suggestion of the author that the system of surface wiring with flexibles so much in vogue on the Continent could be used with advantage here, as whatever dangers may be latent in such a system the results are always plainly visible, and can accordingly be remedied without any delay.

In conclusion I may say that provided the limits of the physical properties of indiarubber are properly understood and a fair amount of common sense used in their application to installation work, very few cases of failure can arise. I would also observe that to ensure reliable results, even with the best of materials, great care and skill has to be exercised in the manufacture of such goods, and we are driven to the conclusion that the buyer's principal safeguard is, after all, to rely upon the services of old and experienced manufacturers who, for the sake of their reputation, will take good care that the goods they supply are suitable for the purposes they are intended for, and not to tie their hands too much by imposing rigid conditions that, however excellent they may be, do not cover all, or even the most important, of the precautions to be observed.

Mr. Beaver.

Mr. C. BEAVER (*communicated*): Excellent as the paper generally is, and ingenious as some of the deductions are, it will be apparent to those intimately connected with the manufacture of flexibles, insulating rubber, etc., that there is a certain lack of intimate knowledge of manufacturing conditions and details which slightly detracts from the value of some of the conclusions arrived at. With regard, for instance, to the matter of the conductivity of small stranded conductors: in Table IV. the S.W.G. diameters of 36 and 38 strand wires are compared with the diameter of tinned wires (presumably measured), and the difference is assumed to represent the thickness of the tin coating. That this assumption is erroneous will be apparent to any one who is accustomed to make, test, and use tinned copper wires, and could easily have been checked by analytical estimation of the tin, or similar means to which I need not now refer. A simple calculation would then show the actual thickness of tin to be unmeasurable.

May I remind the author that the "lay" or pitch of the copper bar which is shown wound around another bar in a close helix in Fig. 3 (and consequently the P.D. between the two bars), is very different from the "lay" of a strand and the P.D. between the wires comprising that strand.

With reference to the remarks in section IV. on "Insulation of Flexibles," I should like to correct the impression given by the author that "cut" strip rubber is the most expensive and generally used strip for high-class cable work. It is neither the one nor the other.

With regard to the author's remarks as to pure rubber insulation withstanding immersion in water, this is largely a matter of the time elapsing between manufacture and the experiment. The pure rubber becomes firmer and more homogeneous in course of time, and the

Mr. Beaver. overlaps become closely sealed up by the natural adhesive properties of the rubber applied under tension.

In several statements on the subject of vulcanised rubbers the author is at variance with facts. Fifty per cent. of sulphur, for instance, is only approached to any extent in ebonite work.

With regard to the "jacket" and "separator" reference. This is hardly modern practice, especially when the former contains 10 per cent. of sulphur.

The author's notes on "Oxidation of Rubber" remind one that, conversely, the rate of oxidation under certain accelerated and controlled conditions may be advantageously used as a guide to the comparative durability of rubbers, etc.

As regards the coefficient of vulcanisation and the deductions which may be drawn from it, the author has apparently overlooked the fact that vulcanised rubbers used for insulating purposes may contain mineral substances, such as litharge or magnesia, which have a considerable effect on the coefficient of vulcanisation. The use of such substances is quite legitimate, and although they tend to give a high coefficient, it is certain that the durability of the rubber is not impaired, but improved by them if used in correct and limited proportions.

The standard hysteresis loop suggested by the author is in principle more scientific and thorough as a test than the elongation test which is sometimes specified, but I cannot agree that good behaviour under this test, even when the sample shows a reasonably good insulation test, indicates durability. It is possible to insulate flexibles with rubbers which will comply fully with stretching and other mechanical tests and give a fair insulation resistance, but will be the reverse of durable. A certain type of foreign flexible is a good instance of this. The pure rubber layer is made from an inferior brand of raw rubber, and has a remarkable degree of elasticity imparted to it by vulcanisation with chloride of sulphur. A thin layer of low grade vulcanising rubber is applied over this, and has the mechanical support of the very elastic rubber beneath it. Consequently, it appears to be durable if judged by mechanical tests, whereas in use it proves to be the reverse.

Cable makers in this country will take exception to the statement that the pressure test usually specified for flexibles is very rarely carried out in practice; and the author will be pleased to know, with reference to his opinion that C.M.A. vulcanised flexibles should have the high-voltage test applied after immersion in water, that this is standard practice and has been so ever since such flexibles were first made.

With regard to the author's remarks under the heading of "Testing of Insulation," the simple chemical tests and determination of percentage of ash are, taken by themselves, almost futile, and a fairly complete analysis is often wide of the mark in its results and interpretations thereof, unless made by a specialist. Even such an one would need much bracing up to agree with the author that the amount of acetone extract "may always be taken as a safe guide as to whether the sample has been manufactured from Para or not."

Mr. Beaver.

Referring to the author's tests on the rubber insulation of flexibles by blowing out the tube of insulation with a bicycle pump, it is, perhaps, only to be expected that when tested to destruction in this way, that the longitudinal joints would fail first, but for all practical purposes the "longitudinal method," as it is called, of applying the vulcanising rubber to small sizes of wire is very efficient. In large sizes it is admittedly less efficient, and lapping methods are generally used in this country for medium and larger sizes of cable.

In conclusion, let me add that makers of good flexibles, etc., in this country would be only too delighted if the author's future work produced some simple series of tests by which easy comparisons could be made by buyers. At present they suffer from the lack of *simple* means of demonstration of the superiority of their goods.

Professor Haldane Gee.

Professor W. W. Haldane Gee (*communicated*): The author's experiments show that much work requires to be done before we are adequately acquainted with the physical properties of rubber. The hysteresis loops are especially interesting, and suggest a means of distinguishing the varieties of rubber. It would be of value to extend the observations both to higher and lower temperatures. There should not be much difficulty in designing an apparatus to record automatically the loops. Shedd and Ingersol[*] have shown that the energy dissipated per cycle due to viscosity falls rapidly with rise of temperature. What happens as the temperature is decreased deserves further investigation. Joule,[†] in his researches on "Some Thermo-dynamic Properties of Solids," mentions "the curious fact that a piece of indiarubber, softened by warmth, may be exposed to the zero of Fahrenheit for an hour or more without losing its pliability, but that a few days' rest at a temperature considerably above the freezing point will cause it to become rigid."

A substance like rubber can have no definite melting point. I have heated Para-sheet for long periods at 100° C. without much softening when determining the specific heat of this substance,[‡] and I have lately studied the influence of a gradual increase of temperature on spread-sheet rubber. The rubber was heated in an air-bath. The following figures show the gradual change:—

Temp. °C.	Condition of Rubber.
90–100	Very slightly sticky to the touch.
145	Sticky, but retains some elasticity.
150–160	Surface melts and the rubber darkens.
170–190	Gradually melts.
240	Can be mixed up and the thermometer easily pushed into the mass.
245	Like a thick lubricating oil.
255	Appearance of decomposition and boiling.
340	Gas evolved which burns with a luminous flame.

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[*] *Physical Review*, vol. xix., 1904, p. 114.

[†] *Phil. Trans.*, vol. cxlix., 1859, p. 91.

[‡] Gee and Terry, "Studies from the Physical and Chemical Papers of the Owens College," vol. i. p. 58 (1893).

Professor Haldane Gee.

The liquid obtained on heating becomes viscid on cooling, but it does not again solidify. It is useful for lubricating stop-cocks.*

The course of the changes on heating depend on the rate of the application of heat, and appear to be modified by the action of air and light.

Mr. Lamb.

Mr. F. LAMB (*communicated*): Whilst much time and care has been devoted to standardising the quality of wires and cables, flexibles have been left pretty much to take care of themselves, with the result that what is at present very largely being used is a foreign made vulcanised flex, the word "rubber" being fortunately dropped, for very little of this material enters into its composition. The mysterious compound is squirted on to the wire through a die, and whilst plastic and flexible when new soon becomes hard and brittle, breaking up and becoming very little use as an insulator.

These remarks only apply to the foreign made flexible so commonly used, which none of the British manufacturers will make. The vulcanised rubber covered flexibles of British manufacture (which are doubtless the samples from which the author has made his experiments) are of a different order, and whilst in my opinion they are very suitable for use in situations where exposed to the weather or very damp places, or where exposed to rough usage, yet for the majority of uses to which flexible cords are applied, such as pendants, wall plugs, etc., I am distinctly of the same opinion as the author and Mr. Sparks, who spoke on behalf of the Wiring Rules Committee, that pure rubber insulation is decidedly better than vulcanised rubber. Hitherto the difficulty has been to point to any standard specification which will insure a reliable pure rubber flexible. This deficiency, however, has now been removed, so that the following statements in the paper are incorrect:—

> Page 37. "The Vulcanised Rubber C.M.A. flexible, which is the *only standard* material on the market."
>
> Page 78. "As things stand at present the Cable Makers' Association *only make* 'C.M.A.' flexibles *in vulcanised* rubber."

The Wiring Rules Committee of the Institution as pointed out by Mr. Sparks, give a specification for pure rubber flexible (see Wiring Rules, I.E.E., July, 1897, page 5, also revised edition, April, 1907, page 11), and this has been embodied in a specification, adopted by the C.M.A., which is as follows:—

ASSOCIATION PURE RUBBER FLEXIBLES.

Conductors.—The conductors to be of annealed, high conductivity, untinned copper to the standards of the Engineering Standards Committee, and of the same sizes as the vulcanised C.M.A. flexible, viz.:—

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* Mr. Baumbach tells me that a mixture for the purpose that is well known in the glass instrument trade is made by heating vaseline to 200° C., and adding small pieces of pure rubber and a little beeswax. It is also useful for applying to ground glass joints.

Mr. Lamb.

23/36s equal to No. 20
40/36s ,, No. 18
70/36s ,, No. 16
90/36s ,, No. 15
110/36s ,, No. 14

The conductor to be covered with one lapping of cotton of 4 mils. radial thickness, then two lappings of pure Para rubber laid on in opposite directions; the total minimum radial thickness of rubber being 20 mils., then two lappings of cotton laid on in opposite directions, each lapping to have a radial thickness of 6 mils., giving a total radial thickness of cotton lapping over the rubber of 12 mils., then braided silk or glacé cotton.

Weight of Rubber in grains per yard of Single Conductor.

L.S.G.	Grains.	L.S.G.	Grains.
23/36	35	90/36	60
40/36	40	110/36	70
70/36	50		

This was placed upon the market last month. It will be seen that the C.M.A. specify the actual thickness and weight in grains per yard of the rubber which should be employed upon this flexible. This is practically as far as the specification can be taken, it having been found impossible, so far, to specify the quality or grade of pure rubber, each manufacturer preparing it in the way he considers best, and upon which his reputation has been made. There is no doubt that in this, as most other things, something must be left to the experience and reputation of the maker.

Mr. Healy.

Mr. L. T. Healy (*communicated*): I agree with the author's opinion that the flexible is the weakest part of an installation. I have found it to be the cause of a large number of electrical fires into which I have made inquiry, and it can undoubtedly become a source of danger to the person through the falling of heavy counterweights and clusters, owing to the severance of the conductors. The whole subject is a very important one, and up to now has been much neglected. There are many contractors who install quantities of flexible of doubtful quality, and comfort their consciences with the thought that it will all be protected by the fuses, forgetting that there are plenty of consumers who are, unfortunately, prone to replace their fuses by such things as pieces of bottle wire. With regard to the effects of bending, I may mention a case which recently came under my notice where some fifty counterweight fittings in an office building rapidly began to fail after about two years' use, the breakage occurring in every instance close to a pulley wheel. The flexibles were of the thin vulcanised class, and upon examination I found the rubber to be in good condition, but the conductors in the parts of the cord which had been most frequently passing over the pulleys were in very bad condition, the strands being not only brittle but in some cases broken up into short pieces. Most of the failures appear to have started by an

Mr. Healy.

arcing between these broken strands and not by a short circuit. I have never found anything suitable for counterweights except pure rubber insulated flexibles of the best possible quality. The greatest amount of bending at lamp-holders is, in my opinion, caused through the use of switch lamp-holders. Mr. O'Gorman has referred to paper mills, and in such places I do not think flexibles should be used at all as I am not aware that, so far, any form of protection has been devised which will effectively resist the attacks of chlorine for even the most heavily insulated of cables.

I do not quite agree with the author's opinion that pure rubber insulated flexibles are best suited for high temperatures. I recently examined some workshop flexible of that kind which had been subjected to a temperature of 98° F. for about twelve months in a linoleum factory, and I found that the rubber had entirely disappeared, the cotton being quite dry. As is usual in such works, there was much acrolein present, and this may, perhaps, have helped to bring about such a rapid deterioriation.

Professor Schwartz.

Professor A. SCHWARTZ (*in reply*): With regard to the relative deterioration of copper conductors insulated with pure rubber and V.I.R., and Mr. Whalley's contention that the hardening effected in the stranding and insulating of conductors can easily be greater than any change due to the presence of sulphur, I would point out that the results given in Table IX. are only a selection from some forty examples which were examined in detail, and that some further examples are given in Appendix E. A consideration of these shows that in nearly every case the conductors have been attacked by the sulphur, and this is evidenced by the discolouration and the brittleness of the outer wires of the strand, whereas with wires insulated with pure rubber this discolouration is absent.

The reason for the temperatures attained by bare wires being higher than those reached with insulated wires in the same time with a given current is to be found in the fact that the cooling surface of the insulated wires is much the larger, and that the insulation itself has a considerable capacity for heat.

With reference to the relative merits of a chemical test, such as that for acetone extract and the stretching test, I have given under Section X., on the "Testing of Insulation," some particulars of the acetone test, as this test is frequently specified both in this country and abroad, but I do not recommend it, as I am strongly in favour of a stretching test in conjunction with a deterioration test at a moderately high temperature.

I hope that further work on the latter lines may enable standard limits to be specified for these tests for given grades of insulation within which limits the results would be regarded as satisfactory. Such a test might replace several of the tests now in use which frequently call for conflicting properties in the material, and would thus be advantageous to manufacturer and purchaser alike.

That the specification of some such limits may not be impossible—

Professor Schwartz

in spite of the forty varieties of Para mentioned by Mr. Whalley, each with its own temperature coefficient—may be gathered from a consideration of Fig. 12, in which C.M.A. flexibles submitted by four firms, and no doubt differing very widely in the constituents of their compounds, fall within limits which differentiate them from the non-association wires and from the samples sold as being "equal to C.M.A. flexible."

The coefficient of vulcanisation is the percentage ratio between the amount of indiarubber and sulphur of vulcanisation present, the addition of such substances as litharge or magnesia, as stated by Mr. Beaver, may have a considerable effect on the state of vulcanisation, but they cannot affect the ratio referred to above. With regard to the state of vulcanisation, I am of opinion that this can be best determined by the hysteresis test, but I think that the more general use of the "vulcanisation coefficient" in specifications would be an advantage as at the present time it is often impossible to tell whether the percentage of sulphur specified is to be calculated on the total contents of the compound or on the rubber contents only.

With regard to the use of cut sheet, I understand that the enterprising foreigner has placed in our markets rolled sheet which is passed between rollers cut so as to imitate the cut marks on cut sheet; apart from this material, however, I believe "rolled" sheet is now largely used.

Mr. Beaver states quite correctly concerning this paper that it is apparent to those intimately connected with cable manufacture that there is a certain lack of intimate knowledge of manufacturing conditions and details which detracts from the value of some of the conclusions arrived at. Any one who, like myself, is outside the rubber industry, will appreciate the difficulty of obtaining such information, as the "trade secret" still looms very large, and inquiries as to details of processes meet with polite but firm refusal.

The 50 per cent. of sulphur referred to by two speakers was instanced as the upper limit for sulphur employed in manufactured indiarubber, and as inferred refers to ebonite.

I am interested to learn from Mr. Lamb that the Cable Makers' Association have placed a standard pure rubber flexible on the market, and trust this material will meet with an extended use.

Pressure should be brought to bear on the manufacturers of ceiling roses, switches, etc., to ensure that the holes in the porcelain are large enough to take the increased thickness of insulation on first-class material; this fact in the past has largely limited the use of C.M.A. flexible, and encouraged the employment of inferior material with thinner wall. This is particularly desirable in view of the extension of the use of flexibles to wiring systems.

The PRESIDENT: I will now ask you to accord to the author a very hearty vote of thanks for the exceedingly useful and valuable paper he has given us to-night.

The resolution was carried with acclamation.

The meeting adjourned at 9·35 p.m.

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